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Abstract — A combination of 30 invited papers and 23 volunteer poster papers presented agroforestry concepts, state-of-the-art agroforestry practices, special applications of agroforestry technologies, regional needs and opportunities for agroforestry in the western United States, and how agroforestry contributes to ecosystem sustainability. A special emphasis in the symposium was identifying system-level needs, how agroforestry generates desired ecological processes and benefits, and how agroecosystem sustainability can be achieved through integrated, transdisciplinary approaches.

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General Technical Report RM-GTR-261

July, 1995

Agroforestry and Sustainable Systems: Symposium Proceedings

W.J. Rietveld, Technical Coordinator

Symposium Sponsors

USDA Forest Service
Rocky Mountain Forest and Range Experiment Station
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The success of this meeting was due in no small part to the willingness of many people to come and share their knowledge and experience. Thank you to all of the speakers, steering committee members, and co-sponsors.

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Sustainable Systems, Agroforestry, and Land Use[1]

Thadis W. Box[2]

Introduction

I appreciate being here among agroforesters. I, too, am an agroforester of sorts. I raise chiles and pecans on a small farm in La Mesilla, NM. This year I am experimenting with about 25 species of flowers and a like number of vegetables and herbs to find a profitable crop that can be grown with pecans.

I am a town trustee for La Mesilla. Much of our historic village is zoned into one and five acre farms. These small farms are becoming building lots for large and expensive houses. The character of our town is changing. If we can develop specialty crops that will allow a family to make a living on small farms, perhaps we can prevent our town from losing the rural ambiance that gives Mesilla its character.

An earlier version of this paper was given in Flagstaff last summer at the ecosystem management symposium. Since I will make many of the same points about sustainability, many of you may think this paper has gone into rerun.

Three years ago I retired as Dean of Natural Resources at Utah State University. I went to New Mexico and taught a graduate seminar on sustainable systems. One week end I climbed a mountain east of Las Cruces and sat in a rock shelter near the place where the oldest corn in the United States was found. As I gazed out over the lush irrigated farms, the housing developments, and the intersection of two busy interstate highways, I wondered if our civilization would also go the same way as those who made the petroglyphs in the shelter I had invaded.

Coming down the mountain, I took a short cut across a dry, barren, west facing slope. There, with no trees anywhere in sight was an ancient stump with weathered axe marks still showing. As the sun went down I sat and wrote:

Stump Near Solidad Canyon

on desert ridge
bare
save yucca
    cacti
        and woody scrub
a stump clings
relict of a gentler time

viejos
cannot remember cedar
on that dry west facing slope
though centuries
    the tree grew
        it fell
in modern times

it stood proud
against drought
    and twisting wind
a rare
dark green dot
on a purple hill

a pioneer
climbed that hill
    swung his axe
removed the life
that clung to stone

did it make

---

[1]*Paper presented at the Agroforestry and Sustainable Systems Symposium (Ft. Collins, CO, August 7-10, 1994).*

[2]*Thad Box is a small farmer and town trustee in La Mesilla, NM. He is also professor emeritus at Utah State University and adjunct Gerald Thomas Professor at New Mexico State University.*

vigas for adobe hut
spokes for wagon wheel
fire to warm a newborn babe
in rare Mesilla snow

the axeman
judge him not
he was a product
of a harsher time

The Native Americans who first tilled our soil, the pioneers who brought European ways, and those of us using land today are all products of our times. Land use is dictated, in part, by our cultural and social values, but our culture is changing, and our land base will be subjected to new uses.

Agroforesters, indeed all of us in natural resources, need to think about changing values, about how land will be used in the future, and about the new worldwide concern for sustainability. We need to back off from trees, crops, and buzzwords such as "green infrastructure" and think about where we fit in the cultural demands on land.

Although we are ecologists who study and teach change in biotic communities, we often ignore cultural change all around us. I speak as one who has had 30 years of happy frustration as a teacher, department head, and dean. During this time students changed, research changed, and funding for education changed. Society itself changed; new public attitudes about conservation and land use came and went, each having an effect on the land.

Cultural changes didn't just affect land use, they altered people's lives. I watched as animal rights activists ruined careers of dedicated wildlife biologists, and as changing values about public land drove regional foresters to retirement before their. My last PhD student, head of the Botany Department at the National University of Somalia, wrote me, "Thanks to God, only one of my children has starved."

Thesis

All these examples fit into my topic today, sustainable systems, agroforestry and land use. This conference will try to determine where agroforestry fits within the larger goal of sustainable land use. My thesis is that we in natural resource management walk a narrow line between the demands of a given culture with its social values, and what it wants from the land, and the need to leave options open for evolving cultures. Sustainable land use will support present and future cultures.

Today I will discuss what I think the real sustainability issues are and how they relate to cultural change. I will not give a college prof lecture on natural processes and ecosystems; you are the experts in that area. I will not argue the case for agroforestry, but will leave that to you who are professional agroforesters. I will paint with the broad brush of societal needs and sustainable land use. In my time allotted, I will:

1. Review the history of conservation and how we came to a global concern about sustain ability.
2. Discuss the human motivation of the past two decades and how it has led to societal concerns and cultural changes affecting agroforestry.
3. Discuss the concept of sustainable development as it relates to agroforestry.
4. Look at some factors affecting future land use.
5. Try to relate these broad factors to trees, crops, and people.
6. Close with some ideas about sustainable systems, cultural change and agroforestry.

Agroforestry and the New Land Management

Many times emotional, marginal issues sidetrack agroforesters and natural resource managers from sustainable land use and social justice. We divide rather than seek a sustainable future. For instance, sophisticated groups are trying to remove commodity use from public lands. Slogans such as "Cattle free by 93" attract headlines. The spotted owl becomes a surrogate for old growth timber. Animal welfare groups and wild horse enthusiasts protect feral horses that in turn destroy public rangeland. In the end we

spend more on feral horses than on battered women. What sets our priorities?

At a recent conference on endangered species in Phoenix, I wrote the following. I call it

Endangered Arizona.

Mexican spotted owl
Gila trout
Northern goshawk

creatures
cowboys
timber beasts
    threatened

Arizona snowbirds
    arrive on dead dinosaurs

Braceros
    die in boxcars

A rabbitbush makes
    the endangered list

Chrysothamnus Molestus

Chrysothamnus molestus, there should be a way to balance conservation with social justice.

From amongst all the emotion, A "New land management" is evolving...using land for societal values. There is a call to shape the future conditions of landscapes for a full diversity of life, ecological processes, human values, and resource uses. This will mean balancing science with social values, economic feasibility, institutional traditions and political muscle.

The "new land management" is a recipe for sustainable land use, but in this country it has largely been associated with protectionist causes. It has most often been directed to concerns dealing with wetlands protection, endangered species, or biological diversity.

It has not become the watchword, as many of us had hoped, for agriculture, agroforestry, natural resource management or world aid organizations. We have yet to relate new land management and sustainability concerns to cultural values, equity issues, and social justice. To have sustainable development we must take the next step.

Where does "new land management" or sustainable development fit into the lives of agroforesters? We are ecologists who know that land sustains our bodies, our children, our life style—we belong to the land. Trees, and crops, and stable systems developed by agroforesters are good for the land. We are proud our objectives support wise land use.

But the land use objectives for most people are the same...wise resource use...but we may differ widely on what wisdom to use. To a Hopi, San Francisco peak is a holy place..a place for spiritual renewal to sustain his culture. To a white recreationist it is a ski slope, a summer cabin, or wilderness..a retreat to sustain another very different set of values. To a forester, it is a place to grow trees; to a shepherd, it is a place to grow sheep. It is a place to support commodity production to satisfy yet another culture of consumers.

Wise use for each group is to sustain the use that perpetuates its cultural values. Only when we are forced to think globally and beyond our own culture does wise use include managing for options to be kept open for new or future uses...in other words, to think about sustainablility.

Sustainability as a World Issue

The quest for sustainability is a worldwide movement. It has many definitions, but all definitions have four central concepts:

1. There must be equity for today's land stewards. Farmers and foresters must be able to make a good living. If they do not have a high standard of living, there will be no tomorrow.
2. There should be equity for future generations. We must leave options open for our grandkids. We must not close out future uses.
3. Long term sustainability must take precedence over short term profit. We must keep the land productive. We must learn to live on the interest without depleting the principle.

4. The fourth central concept is environmental enhancement. We must improve what has been given us. We need to leave the world better than we found it, become active in land improvement.

These are not new concepts. They are the same as those that Aldo Leopold and Hugh Hammond Bennet wrote about sixty years ago. They are the same as those I used thirty five years ago when I talked to the Rising Star Methodist Church on Stewardship Sunday.

The concepts are the same. But the world has changed. And I have changed. Then I had yet to earn my PhD. I did not even know where Somalia was. I had never looked into the eyes of a starving child. And I had never had a friend write "Thanks to God, only one of my children has starved."

Our culture, like me, has changed because of what has happened to it. I believe that the history of conservation in the United States gives us an insight into the current quest for sustainability.

When the first European settlers arrived in North America, we entered an "Era of Exploitation." To conquer the wilderness was right and honorable. Development of the new land was the public policy. Forests were cut. Prairies were plowed. Buffalo were replaced with homesteaders. The railroad connected the Atlantic to the Pacific. A new nation raced to become an industrial giant and a world power.

About the middle of the 19th Century, a few people began to call for saving plants, animals, or land. We entered an " Era of preservation." Yellowstone became our first National Park. Forest Reserves were established. Public policy still embraced growth and development, but room was made to save a little of our resources.

Between the first and second world wars, we entered an "Era of Reclamation." The soil erosion service was formed and the Taylor Grazing Act passed. Make-work projects of the Great Depression constructed terraces, planted forests, built campgrounds, established windbreaks, and tried to rebuild that which had been depleted.

After WWII, as the Cold War made us aware of the possibility of nuclear destruction, we entered the "Era of Environmental Concern."

Rachel Carson's book, SILENT SPRING focused our fears and our attention on ourselves and our families. This book changed the conservation movement forever. What had been a land based movement became a concern for personal health and safety. This new environmental awareness became the moving force for clean air, clean water, organically grown food, and other demands of urban based citizens. It changed the demands made on the land.

I think we may have now entered a yet another era, the "Era of Sustainablility." It grew out of the earth day movement of the 1970s. Originally, the movement was led by powerless kids who distrusted society and its leaders. It was reactive in nature and spawned laws such as NEPA, NFMA, FLMPA, etc. Solutions were based on rules rather than reason. Litigation and lawyers dominated the conservation scene.

The Earth Day Movement became muddled with an unpopular war, new sex mores, free speech movement, changing gender roles, communal living and other evidences of cultural evolution. It lost its power in many diverse, but related movements for which conservation leaders were not ready. Cultural values were being challenged in our society, but most did not view it as a fundamental new direction for conservation. They saw it as simply an extension of the environmental movement.

The examples of cultural change I have seen in Natural Resource students over the past three decades cause me to believe that we are indeed moving into the beginning of the era of sustainability.

During the 1970's I taught an intimate little class of over 340 students called "Natural Resources and Man's Future." It was so popular that I, like the airlines, overbooked it by 15%, thinking that I would have enough absences for any given lecture to allow all to be seated. Instead, I would often find students sitting in the aisles and standing at the back of the auditorium.

The 1970's kids were filled with idealism. They cared. They wanted to save the world. They did not want a job...at least the kind we had to offer in forestry. Foresters and wildlife managers were bad guys who cut trees and wallowed

in blood and guts. The students went into the peace corps, they demonstrated and marched against injustice, and the resisted those in power.

Today, these very people are in power. They are now in leadership positions from the district ranger's office to the White House.

In 1970 students were driven by a fear of nuclear holocaust and found release in such events as Earth Day. Their distrust for authority and their relative powerlessness filled them with frustration. There is evidence that these concerns have carried over today when they are in authority. We can only hope that maturity has leavened their cynicism and distrust.

The students of the 1980's also saw in "the bomb" a real likelihood that their dreams could be cut short. Class size in the beginning natural resource course dropped to less than 100. Students sought material wealth and wanted to make money. They were willing to take any job if it paid well enough. They were not concerned with social issues or the land. In the 1980's fear of extinction led to a "let's get it now" attitude. Concern for personal wealth replaced concern for society. BMW's and MBA's were dominant.

Military Science as a major subject was more popular than forestry and all other fields of conservation combined. Rambo ruled. God lived on Wall Street and drank Perrier water.

The ethic for the 80's was, "greed is good, rules are for fools, and he who has the most toys in the end wins."

The bubble burst in October 1987 when the stock market experienced its greatest one day loss since the crash of 1929.

What cultural values will the next generation bring now that the threat of nuclear destruction has diminished? I don't know.
But whatever they are, the new cultural values will determine how we use our land base to meet societal needs. Sustainable development depends on what we demand from the land.

Sustainable Development

Sustainable development became a world issue with the awakening of global economic and environmental interdependence. As groups of nations moved toward "Economic communities" they found that trade and national economies can be regulated only with great difficulty. Environmental regulation was even more difficult. Environmental disasters knew no national borders. They cut across political subdivisions.

A number of international organizations are addressing the problem of sustainable development. The World Commission on Environment and Development issued a report as early as 1983 on global development problems. The Commission was an independent entity of United Nations. Some of their findings were optimistic: human life expectancy was increasing, infant mortality was decreasing, adult literacy was climbing, scientific and technical innovations were promising, and global food output was increasing faster than population growth. However, they also reported that topsoil was eroding faster than it formed, forests were declining, air pollution was smothering our cities, ozone protection was diminishing, and toxic substances were more abundant in water supplies.

They concluded that the gap between the rich and the poor was increasing and that the land use in 1983 was not sustainable.

Now, a decade later, the Commission findings are still valid. Several major conferences, the latest last year in Brazil, have tried to get global consensus on a plan of action that will allow the world to develop in a sustainable fashion.

Sustainable land use means implementing a policy that meets the needs of people today without destroying the resources that will be needed in the future. Development cannot be sustained on a deteriorating environmental base. For national economies to grow and be profitable, the natural resource base must be maintained.

Sustainable Land Use depends, in part, upon determining the ecological carrying capacity of the land, determining what people want and need from the land, and a political and economic system that matches what people want and need with the land's ability to produce the desired goods and services.

While the potential ecological carrying capacity of the land remains relatively stable, the cultur-

al and social demands on the land are constantly changing, causing the actual carrying capacity to fluctuate widely through time. Therefore, the overriding element for those attempting to manage development is coping with change. The key issues are:

1. Determining what society wants from its lands with inevitable changing values, changing demographics, and changing economics.
2. Achieving orderly transition and community well being in an internationalizing and amenity oriented economy.
3. Developing common language, measures, and forums for identifying and evaluating tradeoffs: ecological, economic, fiscal, human, and social.
4. Shifting from reductionist and disciplinary work to synthesis and interdisciplinary analysis of systems.
5. Defining the issues to reflect fairly the wants and needs of society while protecting the sustainable land base.

The concept of sustainable development in rich countries is most often embraced by conservation groups and organizations. At the same time, these rich countries are using a disproportionate amount of the world's resources. Unless sustainable development is linked to basic issues of equity, social justice, and community stability for poor people, sustainable development will fail.

But can we in America relate to sustainable human lifestyles when we are hooked on a consumption society? Our development is not sustainable because our domestic policies are too closely linked to low food prices, artificially cheap oil, and consumption encouraged to promote growth. With the collapse of the Soviet Union and recessions in Japan and western Europe, we are once again cast as the world's leader. Opportunities have never been better for us to lead the world onto new plateaus — if we relate all new issues to sustainability. However, we can only lead if we make our own lifestyles sustainable.

Future Issues for Agroforesters

No one knows exactly what the future holds. However, I am certain that there will be several issues that will dominate much of our attention in the future. I will discuss four of these.

Demographics

First, the human population, especially its demographics, will affect sustainable land use. The primary question for my generation was, "Who will feed the hungry world?" We have made major accomplishment in this area, to the point where we have an embarrassment of surpluses in some countries. But the problem of feeding the human population remains, only the time frame has changed. Even with our abundance of food, some 40,000 people die each day of starvation and disease. In a month more people than live in New Mexico will die from nutrition related ailments.

There are other pressing demographic issues besides balancing human numbers with food supply. The gap between the haves and the have nots is increasing. Poor countries are growing 4 times as fast as rich countries; 4 out of 5 babies are born into poverty. Sustainable land use must relate to this poverty gap.

Sustainable land use, equity in this generation, means feeding those less fortunate than we whether they are in Somalia, or Bosnia, or Northern Colorado.

Economic Trends

Rich countries are not growing...they are growing old. Poor countries have young populations of mostly non-white people. In the United States, wealth is concentrated in a few, usually older people.

The United States has moved from the world's largest creditor nation to its largest debtor nation. The global financial center has moved from Wall Street to somewhere on Pacific Rim.

Our markets and our labor are in poor countries, but they are unable to buy. Their standard of living must be raised if they are to participate in sustainable development.

Sustainable Land Use, equity for future generations, depends on world peace and world trade.

Material Science and Technology

We live in a world where designers imagine a product, engineers specify the characteristics of the components, and chemists create the building materials from polymers, graphite, ceramics, or whatever combination of elements can produce the required strength and aesthetic qualities. No longer does the designer buy two by fours and then let them determine the final product; the final product is based on the creators imagination and skills. The demand for producing natural building products such as wood, wool, and cotton will not necessarily determine land use. But the new synthetic materials must be constructed from existing elements, and all will require increased levels of energy input.

To achieve sustainable land use, the development of alternative energy sources needs to be global. If in this decade all rich countries stopped burning hydrocarbons, still the increase in coal burning as China and Eastern Europe expand their industrial output would likely keep global warming on its present upward trend.

Sustainable Land Use, long term stability, means adapting new materials and adjusting land use through a combination of ecology, economics, and technology.

Philosophical Trends

Of the world's 10 largest countries only 3 are "Christian" in philosophical thought. In the past, world development, sustainable or otherwise, has largely been the product of western thought patterns of growth and development. The philosophical implications of a global change away from Judeo-Christian attitudes about development will have profound effects on sustainable land use.

The most obvious trends are an increase in animal rights activities and a wider acceptance of vegetarianism. However, much more important changes will occur with different concepts of equity, beauty, property ownership, productivity, and work.

Even now, work is not what we do, but is what we can imagine. Vladimir Horowitz, one of the greatest pianist of all times, died a few years ago. A clever computer programmer can make a synthesizer play Horowitz, Chet Atkins, Alabama, the Grateful Dead, or even Bob Wills. But she cannot make the computer imagine the music.

Science fiction writers tell us of transferring material directly from one brain to another. The android, Mr. Data, on Star Trek has all the past knowledge and human experience stored on his computer chips, but he lacks human emotion and a philosophical base. A Mr. Data could provide all the information needed to make the world better, but he could not define better for us.

Sustainable Land Use, environmental enhancement, will depend on what our concept of "better" is. Our philosophical base will be the key element, not our technology.

Now for some final thoughts on sustainable land use and cultural change. Sustainable land use ANYWHERE is linked to cultural demands. Cultures change. Land use changes. If what cultures want from the land is not compatible with the ecological base, cultures cannot succeed. Balancing land capability to cultural demands will be controlled by what we can imagine, creativity, vision. And all these are enhanced by education.

There are some simple steps in education...the creation of a vision: 1) Make people aware of the situation and give them the facts, 2) Give them problem solving skills, 3) Give them a bag of tools, 4) Inspire them to do something about the situation.

What we need to do is to create new visions of what the world can be. We need to tie science and application together:

1. <u>Identify the problem.</u> What is causing non-

sustainability on our planet or in our back yard garden?

2. Set priorities. What problems should we tackle first that will really make a difference? For example global warming and the greenhouse effect may be a policy problem rather than one for individual action. If everyone planted a tree, if all the rain forests are saved, and we do not change fossil fuel use all will be for naught.
3. Improve our bag of tools. Do good science. Synthesize and integrate. Tie ecology, economic development, and social justice together. Accept social sciences as land management tools. Improve our application of science.
4. Inspire. Inspire to make something happen. Inspire to create new visions of what may be.

We are having trouble creating new visions because we are unable to relate to new cultures and social values. Our traditional approaches have been based on the cold war fears, protect ourselves from world communism and promote consumption for continued growth and economic gain.

New advocates for sustainability may come from diverse groups with varying immediate goals. Environmental groups demand natural resource protection. Commodity groups want sustained production. The underemployed, the hungry, the have-nots wish for social justice and a sustained fair wage.

The new support is not always scientifically credible. We often get bogged down defending practices or positions that are equally incredible. We mix scientific credibility with social acceptance or political correctness. We try to apply past solutions to current problems.

We forget that we, like the pioneer who chopped down the cedar tree, are products of a different time. Our success will be determined by our ability to adjust, change, lead.

If we concentrate on education, creativity, application, we can move to a yet higher plateau.... a higher plateau where social justice is balanced with resource use, where development is truly sustainable.

Agroforestry will have a place in sustainable land use if we remember:

- equity for today's generation
- a better life for our grandkids
- leave options open for those who follow us
- leave the world better than we found it.

But we will not have, indeed we do not deserve, public support if we continue business as usual, continue to organize our programs of development around narrowly drawn issues. We will fail if we underestimate the worldwide support for sustainability. I hope that we in agroforestry and natural resources in this generation set the stage for a better world.

I was fortunate to have had a career dealing with the land. I am proud to have been a university teacher and a conservationist. I am struggling to be a different kind of teacher today. I appreciate your kindness in letting me spout my biases. Thank you for asking me here today.

Agroforestry: A Maverick Science and Practice[1]

W.J. Rietveld[2]

Agroforestry is the intentional integration of agriculture and forestry practices to attain diversified and sustainable production systems. Agroforestry practices include riparian buffers, streambank bioengineering, alley cropping, tree/pasture systems, windbreaks, living terraces, living snowfences, tree/specialty crop systems, and wildlife habitat. Benefits are increased crop production, alternative crops and diversified rural economies, improved water quality/soil erosion/sediment control, filtering and biodegrading excess nutrients and pesticides, reduced flooding, microclimate moderation, and diversified habitats for wildlife and humans. Outcomes include diverse, resilient, and sustainable farm enterprises and communities, and viable alternatives to more onerous and costly regulatory approaches to address societal environmental concerns such as soil erosion, water quality, and biodiversity.

This is how we describe agroforestry today. It's a holistic concept that is designed to be compatible with sustainable agriculture, natural resource conservation, environmental concerns, and people's economic and social needs. Agroforestry is pragmatically marketed as "working trees for agriculture" — planting the right tree in the right place for a specific purpose.

As recently as five years ago, we were still stuck in the mode of selling forestry to farmers, with only modest success. Granted, there is a segment of landowners who are enthusiastic about tree planting; we will have their interest no matter what we do. But, for the remaining 90% of the landowners, our message and approach catered more to our needs than to their needs.

When we started using the term "agroforestry", it was generally seen as "traditional practices in developing countries". But we overcame that perception by redefining agroforestry to make it address our domestic issues and needs, as described in the first paragraph. That approach has been very successful, and today agroforestry is a familiar term in the United States. Agroforestry is far more than a name change. Now, worldwide, we are developing a scientific basis for agroforestry as an integral part of sustainable agricultural land-use systems, tailoring it to the needs of natural resource management, and addressing critical environmental and human issues.

Paradigms continue to change, and we need to continue to change and adapt. Business as usual is not acceptable for the future. Now we need to take agroforestry one more step. We need to emphasize the need for an ecosystem-based approach and focus on watersheds. From that perspective, it is easier to see and appreciate the benefits from agroforestry, and to get stakeholders to work together. Agroforestry contributes substantially to generating the ecosystem diversity, ecological processes, and buffer zones important to long-term sustainable systems. Sustainable development is the goal, an ecosystem-based approach is the process, and watersheds are the management units. In order to integrate technologies and address the needs of the resource at a watershed scale, cooperation and linkages are needed among disciplines, programs, and agencies.

Agroforestry appeals to a broad audience, and therefore has many customers. The landowner is the primary customer, and for him/her agroforestry will always need to make good economic

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[1]*Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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and practical sense. But there are other important and influential customers for agroforestry. They include our cousins in other agencies, institutions, and organizations; policy makers; and the public. The broader ecosystem-based/ watershed-scale concept of agroforestry makes good sense to them. The multiple benefits from agroforestry are more apparent, more valuable, and more recognized when we consider the contributions to the system at a watershed scale. Its more difficult to get attention for the monetary and conservation benefits from one patch or line of trees (a practice), but we can show substantial and multiple benefits from numerous practices integrated into the system at larger scales. Think of agroforestry in terms of "field and landscape buffer systems" that occupy approximately 5% of the land area. It is the ecosystem infrastructure that contributes substantially to ecosystem diversity, health, resilience, and sustainability.

It is time to move on to a systems approach. We need the ability to manipulate the component parts with full knowledge of the impacts on the entire system. A watershed analysis approach would provide stakeholders a common arena to work together to identify problems, evaluate alternatives, target treatments, and monitor trends. We can readily develop watershed-scale decision-support tools that will show what the benefits will be and guide the selection of alternative practices and locations based on desired outputs.

We are already seeing outcomes from this approach. In the 1995 Farm Bill debate, policy recommendations from sustainable agriculture and environmental advocacy groups emphasize targeting any extension of the Conservation Reserve Program (CRP) to lands and practices that provide multiple and long-term benefits to multiple stakeholders. Landowners, interest groups, the Congress, and the public have begun to recognize the multiple benefits of trees and shrubs, integrated into farming systems, to help attain ecosystem sustainability. Agroforestry is one of the few alternative technologies that can simultaneously provide economic, environmental, conservation, and social benefits to multiple stakeholders.

If agroforestry has so much potential, why do I refer to it as a maverick science and practice? The dictionary defines a "maverick" as "an animal without an owner's brand; a calf separated from its mother; a dissenter". The comparison of agroforestry with a maverick is so close, its almost frightening. How is agroforestry a maverick science and practice?

First, agroforestry is non-traditional. When you swim against the current, its hard to get anywhere, and you can easily be swept away. It conflicts with the accepted paradigm of modern, efficient agriculture, e.g. "trees get in the way", and "trees can't compete economically as an alternative crop." However, that perception is changing as we document the benefits from agroforestry and more emphasis is placed on sustainability and diversification in agroecosystems.

Second, agroforestry is not recognized. In the forestry camp, agroforestry is seen as "interesting, but not our highest priority". In the agriculture camp, people do not understand the benefits of agroforestry. The public, including landowners, are the same way. All of these groups are amenable to alternative approaches, the message just needs to make sense and have value.

Third, agroforestry is cross-cutting. Agroforestry cuts across agencies, programs, and disciplines, and does not have a distinct home. The present structure and programs are not designed to deal with a cross-cutting science and practice like agroforestry. Without cooperation across agencies and disciplines, agroforestry is an orphan — no one owns it.

Agroforestry is in a predicament with unique needs and challenges, and requires a unique approach. The challenges for agroforestry are analogous to those faced by urban forestry during its formative years during the 1970's and 1980's. It was dismissed as "not forestry", and "there's no room for another new program." Through a persistent effort and a series of steps spanning 20 years, urban forestry gained recognition and support, policies were set, and programs were created and funded. Today, urban and community forestry is a $25 million/year program.

Urban forestry took over 20 years to get recognition, support, authorized programs, and funding. Will agroforestry follow the same

bumpy road? Yes, but with some caveats. First, urban forestry had no existing infrastructure for program delivery. Agroforestry does, but it needs to be "reinvented" to address the unique nature of agroforestry. Second, urban forestry has tremendous grassroots support. Where is the grassroots support for agroforestry? The bottom-line is that agroforestry can learn a lot from the urban forestry experience. We need to build understanding, acceptance, and support for agroforestry. The community of interest for agroforestry needs to accomplish it; no one is going to volunteer to do it for us.

Specifically, what is needed to get understanding, acceptance, and support for agroforestry? Here is my list of ideas:

1. **Agroforestry must address important issues.** It is clearly aimed at the pervasive issues of land depletion, water quality impairment, loss of biodiversity, and the need for sustainability and rural economic diversification.
2. **Agroforestry must be pertinent to customer needs.** Agroforestry provides numerous economic, environmental, conservation, and social benefits to a variety of customers.
3. **Interagency cooperation and coordination are necessary** to overcome institutional barriers, provide a mechanism to commit to agroforestry, and effectively/efficiently develop and deliver agroforestry programs.
4. **Leadership** is needed to provide a driving force to facilitate partnerships and catalyze cooperation to develop agroforestry and get it applied.
5. **Multi-disciplinary teams** are needed to develop and apply agroforestry.
6. **Visibility** is needed to bring agroforestry to the attention of policy makers and administrators to gain their support. Agroforestry needs champions.
7. **Regional Associations** are needed to provide a forum to link scientists and practitioners to enhance communication and technology transfer.
8. **Grassroots support** of agroforestry is needed from landowners, industry, conservation organizations, and special interest groups. Policy makers need to hear it from the people who use it (and want it).
9. **Focused programs and funding** are needed to accelerate agroforestry development and implementation, and to address the unique needs and challenges of agroforestry.
10. **Research and development** are needed to develop improved agroforestry technologies, information, decision/application support tools, and integrated systems.
11. **Technology transfer** is needed to provide printed materials, demonstrations, applications projects, assessments, syntheses, and tools to accelerate putting into practice what we already know.
12 **Education and training** of technical assistance personnel is needed to enhance their capability and priority for providing agroforestry support.

I don't see anything on this list that can be ignored if we are to be successful. Its important that we focus on our customer's needs and focus on outcomes. The immediate need is to get agroforestry on the ground through a concerted effort to put into practice what we already know.

Lets go back to the challenges confronting agroforestry: it's non-traditional, lacks recognition, and cuts across agencies, programs, and disciplines. The only way we can advance agroforestry is through teamwork. We need to work together to develop broad-based understanding, acceptance, and support for agroforestry. We need to break barriers and build bridges. We have come a long ways; we still have a long ways to go. Lets work together to develop and deliver agroforestry.

Riparian Buffer Systems in Crop and Rangelands[1]

Richard C. Schultz, Thomas M. Isenhart, and Joe P. Colletti[2]

Abstract — Riparian ecosystems occupy a narrow belt of land along streams and around lakes and wetlands and are characterized by plant and animal communities that are dependent on close proximity to water. These ecotones function as buffer zones for materials moving from the uplands toward the surface water. They control stream morphology and ecology and also maintain landscape biodiversity by providing diverse habitats and corridors for animals and plants. Most of the riparian zones in the Midwestern agroecosystems and arid and semi-arid western rangelands have been extensively impacted by agricultural cropping and grazing activities. These impacts have generally decreased water quality, impaired riparian and instream biodiversity, increased water quantity, and modified the timing of streamflow. Riparian zones are generally resilient because of their moist, moderate and fertile environments. With proper management, this resiliency can be sustained. Proper management should include construction or restoration of multi-species buffer strips and deferred or rotational grazing or exclusion of livestock. Several riparian zone restoration and management strategies are discussed.

Introduction

Riparian zones lie between aquatic and upland ecosystems in landscapes and play a critical role in the hydrology of watersheds (Smith 1992; Kira 1988; Lowrance et al. 1985a; Lowrance et al. 1984a). Because of their landscape position and their more frequent natural disturbance, riparian zones contain sharp biological and physical gradients. This results in a plant community that often contains a mosaic of age classes of upland species and species adapted to abundant water (Anderson and Masters 1992; Gregory et al. 1991). The typically long and narrow nature, along with the unique physical and biological processes, allow riparian zones to act as "strategic" buffers between upland and aquatic ecosystems (Osborne and Kovacic 1993; Nutter and Gaskin 1989; Lowrance et al. 1985b). Although a riparian zone may occupy as little as one percent of the land area in the arid watersheds of the west, these ecosystems are among the most productive in the landscape (Chaney et al. 1990). This paper will describe the important riparian ecosystem functions, present conditions of riparian zones in Midwestern agroecosystems and semi-arid and arid rangelands, and strategies for their restoration and management. Strategies discussed include the multi-species riparian buffer strip management system and methods of seasonal, deferred and rotational grazing.

Riparian Zone Functions

Riparian zones provide important links between the terrestrial upland ecosystems and aquatic stream or lake ecosystems (Osborne and Kovacic 1993; Franklin 1992; Elmore 1992; Gregory et al. 1991; Welsch 1991; Lant and

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Roberts 1990). Some of the most important functions in agricultural and grazing landscapes include filtering and retaining sediment, immobilizing, storing, and transforming chemical inputs from uplands, maintaining streambank stability, modifying stream environments, and providing water storage and recharge of subsurface aquifers.

Sediment Filtering and Retention

About 1.4 mt of sediment are delivered to surface waters in the US every year (Welsch 1991). Croplands account for 38 percent of this sediment while pastures and rangelands account for 26 percent (Welsch 1991). Excess sediment impairs aquatic life, clogs stream channels, reduces reservoir flood storage and contaminates water supplies. Riparian forest and grass communities can filter up to 90 percent of the sediment entering them from the uplands. The vertical structure of the standing plants and the organic litter provide frictional surfaces which slows water flow causing the sediment to be deposited (Magette et al. 1989; Dillaha et al. 1989; Cooper et al. 1987; Lowrance et al. 1986, 1988; Peterjohn and Correll, 1984; Brinson et al. 1981; Mahoney and Erman 1984). High infiltration rates of undisturbed riparian zone soils allow finer sediments and associated nutrients to enter into the soil before reaching the stream. As a result, as much as 80 percent of the phosphorus adsorbed to sediment particles can be filtered from surface runoff by forested riparian buffer zones (Welsch 1991). However, riparian zones are effective for sediment retention only if surface flow through them is maintained as sheet flow. Concentrated channel flow can destroy the continuity of the filter strip.

Longevity of sediment trapping ability varies between forest and grass communities. Cooper et al. (1987) and Lowrance et al. (1988) suggest that forest riparian buffers can filter sediments over long periods whereas Magette et al. (1989) and Dillaha et al. (1989) indicate that grass buffer strips may have short sediment filtering lives. If cool season, short grasses are replaced by native, tall prairie grasses, grass buffer strips have a longer sediment trapping life span (Schultz et al. unpublished data). In either case, sediment accumulation along the edges of any riparian buffer strip will have to be periodically renovated and areas of concentrated flow will have to be modified. Filtration of sediment from flood flows will also build streambanks and can create wet meadows and floodplain ecosystems (Chaney et al. 1990).

Nutrient and Chemical Processing

A growing body of evidence indicates that vegetated riparian zones can be effective at immobilizing, storing, and transforming chemical inputs from uplands. One of the major problems associated with agricultural production in the US is movement of fertilizers and pesticides from the uplands into the surface waters of the landscape (Knox and Moody, 1991; Lant and Roberts 1990; Felsot, 1988). Nitrogen is one of the most pervasive of the chemical non-point source (NPS) pollutants. Croplands contribute 43 percent of the annual nitrogen input to surface waters while pasture and rangelands contribute 25 percent (Welsch 1991).

Riparian forests and grass communities reduce nitrogen by 40-100 and 10-60 percent, respectively (Petersen et al. 1992; Osborne and Kovacic 1993). The methods of chemical removal in riparian systems include plant and microbial uptake and immobilization, microbial transformation in surface and groundwater and adsorption to soil and organic matter particles. The effectiveness of these processes will depend on the age and condition of the vegetation, soil characteristics such as porosity, aeration, and organic matter content, the depth to shallow groundwater and the rate with which surface and subsurface waters move through the buffer strip (Groffman et al. 1992; Lowrance 1992).

Plants can assimilate and immobilize nutrients such as nitrogen (N) and phosphorus (P) as well as heavy metals and pesticides. However, to be effective at removing these chemicals, plants must have access to high water tables or there must be sufficient unsaturated flow (Ehrenfield 1987).

Plants will also not remove chemicals from water which is moving too rapidly over the surface or as preferential flow through macropores. Correll et al. (1994) and Schultz et al. (unpublished data) have observed that nitrate is not effectively reduced in coarse textured soils under high flow events when much of the annual N loading of the buffer zone might be taking place. In addition, riparian vegetation will be an effective sink only as long as the plants are actively accumulating biomass. Once annual biomass production is equal to or less than litterfall, there will be no new addition to the standing biomass sink. Plants must be harvested before that time if they are to remain viable agrichemical sinks. However, release of pollutants by litter decomposition may be beneficial if the vegetation removed the nutrients from the groundwater, where the potential for transformation to harmless by-products is often quite low (Groffman et al. 1992; Lowrance 1992).

Microbial processes are also important in reducing NPS pollution in the landscape. Microbe will assimilate and immobilize NPS pollutants but their rapid turnover and relatively small biomass may make this a minor sink. Microbes may also degrade many organic compounds such as pesticides. However, the metabolic breakdown of these organic compounds is dependent on readily available organic matter in the soil (National Research Council 1993).

Under anaerobic conditions microbes can denitrify nitrate into harmless nitrogen gas. This process has been found to occur in surface soils of riparian forests (Haycock and Pinay 1993; Jordan et al. 1993; Groffmann et al. 1992; Ambus and Lowrance 1991; Corell and Weber 1989; Jacobs and Gilliam 1985; Lowrance et al. 1984B; Peterjohn and Correll 1984) and seems to be dependent on the availability of carbon (Starr and Gillham 1993; Obenhuber and Lowrance 1991; Parkin and Meisinger 1989; Slater and Capone 1987: Smith and Duff 1988; Trudell et al. 1986). Wider vegetated buffer strips are usually more efficient at removing nutrients (Petersen et al. 1992). However, the long-term nutrient removal effectiveness of buffer strips is not known (Hanson et al. 1994; Osborne and Kovacic 1993). Wetlands that may be an integral part of integrated riparian management systems are highly efficient at denitrification because of their large quantities of organic sediments and decaying plant material (Crumpton et al. 1993).

Streambank Stability

When riparian vegetation is drastically modified or removed, streambanks become unstable and collapse, resulting in changes in channel width and structure (Fleischner 1994; Elmore 1992; Armour et al. 1991; Platts 1989). The woody and fibrous roots of plants growing on the streambank provide strength to hold the streambank in place. Plant roots increase soil stability by mechanically reinforcing soil and by reducing the weight of soil through evapotranspiration (Waldron and Dakessian 1982). Deeper rooted plants extract more water from greater soil depths than shallow rooted plants. Woody plant roots provide superior soil stabilization when compared to herbaceous plants because of their deeper rooting habit and their larger roots (Waldron et al. 1983). Woody roots provide protection against the hydraulic pressures of high flows while fibrous roots bind the finer soil particles (Elmore 1992). Tall grass prairie species are more effective than short cool season grasses at providing streambank stability because of their deeper fibrous root systems. There can be up to nine times more roots in the top 45 cm of soil and up to five times more at 100 cm depth for prairie grass species than for cool season species (Schultz et al. 1995).

Instream Environment

Loss or modification of riparian vegetation is one of the major reasons for the reduced quality of the aquatic environment throughout the United States (Fleischner 1994; Sweeney 1992; Menzel 1983). Riparian vegetation controls the quantity and quality of solar radiation reaching the water surface in lower order streams and thus influ-

ences autochthonous production and water temperature (Gregory et al. 1991; Sweeney 1992; Sinokrot and Stefan 1993). Organic matter input into the stream from riparian vegetation is an important energy source for aquatic organisms. Differences in quality and quantity of organic matter inputs between conifer and deciduous forests and between forests and grasslands often determine the structure of the invertebrate populations in the stream (Bilby and Bisson 1992; Gregory et al. 1991; Gurtz et al. 1988; Oliver and Hinckley 1987; Behmer and Hawkins 1986). Finally, large woody debris in the stream channel influences the physical structure of the channel by controlling the distribution of pools which store and detain sediments and riffles which oxygenate the water (Sweeney 1992; Gregory et al. 1991; Bisson et al. (1987). The more riparian zones can perform these "natural" functions the more diverse, productive, and resilient the instream ecosystem will be (Franklin 1992).

Water Storage and Groundwater Recharge

Vegetated riparian zones function to slow flood flow which allows water to spread and soak into the soil thereby recharging local groundwater and extending the baseflow through the summer season (Elmore 1992; Wissmar and Swanson 1990). In the West many streamside aquifers go dry later in the season because of poor livestock management on riparian zones (Elmore 1992). In the Cornbelt states of the U.S., channelization and tile drainage lower watertables to reduce the chance of out-of-channel flood flows in the riparian zone (Menzel 1983).

Riparian ecosystems are also important travel corridors for both animals and plants. They provide lush and diverse habitat for wildlife and because of their rich, moist microenvironments they are often the source of both upland and bottomland plants species in the landscape especially after upland perturbations (Naiman et al. 1993; Gregory et al. 1991).

The functions and processes of long, narrow riparian zones are extremely important to sustaining quality agricultural landscapes. These narrow ecosystems intercept and process nutrients, sediment and organic matter, which originates from the adjacent land. If these materials reach the stream they reduce water quality and their loss from the uplands reduces productivity. Because of the importance of these riparian ecosystems in cropland and rangeland ecosystems, effective methods for saving, restoring and managing riparian zones must be developed (National Research Council 1993).

Present Condition of Cropland and Rangeland Riparian Zones

Midwestern Cropland

The highly productive crop production regions of the midwest are a mosaic of crop and pasture lands, human habitations and small remnants of native prairie, wetland, and forest ecosystems. Most of the natural ecosystems have been converted to intensively managed agroecosystems in the twelve states ranging from Ohio to the eastern portions of the Dakotas, Nebraska, and Kansas, and from the southern portions of the Lake States to the northern half of Missouri. In Iowa, for example, 99% of the prairie and wetland area and more than 80% of the forest area have been converted to other uses (Bishop and van der Valk, 1982; Thomson and Hertel, 1981). Ohio, Indiana, Illinois and Missouri drained more than 85 percent of their wetlands by the mid 1980's (Dahl et al. 1991). In most of the midwest region less than 20 percent of the natural prairie, forest, wetland and riparian ecosytems still exist (Burkart et al. 1994). In a typical watershed in central Iowa about 50% of the total length of stream channel may be cultivated with corn and/or soybeans to the bank edge. Another 30% of the length may be in pasture, most of which is overgrazed (Bercovici, 1994). Annual soil erosion is greater than 6.7 Mg/ha in much of the central part of this region and in some areas is greater than 11.2 Mg/ha despite that fact that many of these same

areas have over 50 percent of the land in upland conservation practices (Burkhart et al. 1994). Because they have little other perceived value, many kilometers of Midwestern riparian zones have livestock fenced into them as a management practice. Livestock under these conditions do extensive damage to the stream channel, the streambanks and the riparian zone.

Modern product-oriented agriculture has put this midwestern agroecosystem at risk. The production-oriented function of this landscape has produced unintended and undesirable environmental consequences. These include loss of biodiversity, detrimental alteration of waterways and groundwater aquifers and loss of significant portions of the productive topsoil resulting in greater need for fertilizer and energy inputs. Non-point source pollution has become so pervasive because of rapid surface and subsurface water movement and reduced soil residence time of agrichemicals. It is now apparent that upland conservation practices alone are not effective in reducing NPS pollution (Burkhart et al. 1994; National Research Council 1993). Field and landscape buffers, including riparian buffer zones, are also needed to develop a sustainable agroecosystem with improved soil and water quality (Castelle et al. 1994; National Research Council 1993). However, major issues about buffer strip efficiency and design must be clarified before they can be effectively implemented. These issues include: plant species selection and efficiency; optimal widths for various buffer strips; longevity of the buffer zones as nutrient and sediment sinks; criteria for identifying riparian zones in need of buffers; and criteria for long-term management of buffer strips (Castelle et al. 1994; National Research Council 1993; Osborne and Kovacic 1993).

Western Rangeland

Recent reviews by Fleischner (1994), Kauffman and Krueger (1984), Elmore (1992) and Chaney et al. (1990, 1993) identify livestock grazing as having dramatically changed riparian zones in the rangelands of the west. The changes by livestock have been so great and cover so much of the western landscape that it is even difficult to determine what the natural vegetation was or what the effects of livestock grazing has been (Fleischner 1994). Riparian zones in the semi-arid and arid West are probably even more important to the overall landscape than they are in the cropland of the Midwest. While they occupy less than one percent of the landscape they are the most productive and biodiverse ecosystem in that landscape. More than 75 percent of the wildlife in many of these watersheds depends on the riparian zone for existance (Chaney et al. 1990). Riparian ecosystems in the arid and semi-arid west also function to filter sediment, stabilize streambanks, store water and recharge subsurface aquifers (Fleischner 1994; Elmore 1992; Chaney et al. 1990). Excluding isolated examples, the condition of the riparian zones throughout the semi-arid and arid west are the worst they have been in history (Chaney et al. 1990).

Livestock tend to congregate in the riparian zones where there is succulent vegetation, shade, and water. In the process they compact the soil and destroy the bank by climbing into and out of the stream. Livestock will also rub, trample, and browse the vegetation, and relieve themselves directly in the stream. This results in the widening of the stream channel, decreasing average stream depth and increasing average stream temperature, and sediment and nutrient loads. Alterations in the timing and volume of streamflow and lowering of the local water table also occur (Kauffman and Krueger 1984; Platts 1981). These activities along with the lack of management strategies unique to riparian zones are responsible for the poor condition of these riparian ecosystems (Armour et al. 1991). Many kilometers of Midwestern riparian zones have also suffered the same fate.

In summary, riparian zones in crop and rangeland landscapes are presently in poor condition. However, these ecosystems are among the most resilient in the landscape because of their moist, fertile and microclimatically less extreme conditions and therefore should respond well to mangement and restoration activities. Research should be accelerated to develop design and management standards for landscape buffer zones in

the crop and range landscapes (National Research Council 1993; Armour et al. 1991). It is especially important to understand the dynamics of riparian zone processes, to describe the impact of good management of riparian habitats on all natural resources and to develop predictive methods to determine optimal widths and management intensities needed to accomplish specific soil and water quality objectives.

Restoration of Riparian Zone Conditions

Cropland Remediation

The United States Department of Agriculture (USDA) Forest Service (FS) and the USDA Natural Resource Conservation Service (NRCS) have developed guidelines for riparian forest buffers (Welsch 1991). These buffers have three distinct zones. Zone 1 is a 5 m wide strip of undisturbed mature trees that begins at the edge of the streambank and provides the final buffer for materials moving through the buffer strip and directly influences the in-stream ecosystem by providing shade and large and small organic matter inputs. Zone 2 is a 20 m wide zone of trees managed to provide maximum infiltration of surface runoff, and nutrient uptake and storage while also providing organic matter for microbial processing of agrichemicals. Zone 3 is a 6 m wide zone of grazed or ungrazed grass which filters sediment from sheet flow generated in the uplands and causes large quantities of water and agrichemicals to infiltrate into the biologically active rooting zone where nutrient uptake and microbial processing occur. The FS and NRCS guidelines were developed after extensive reviews of forested riparian zones in the eastern United States. However, the guidelines and model may not be well suited to the agroecosystems of the Midwest and Great Plains where many smaller order streams drain highly modified (prairie) agricultural and grazed landscapes with few trees.

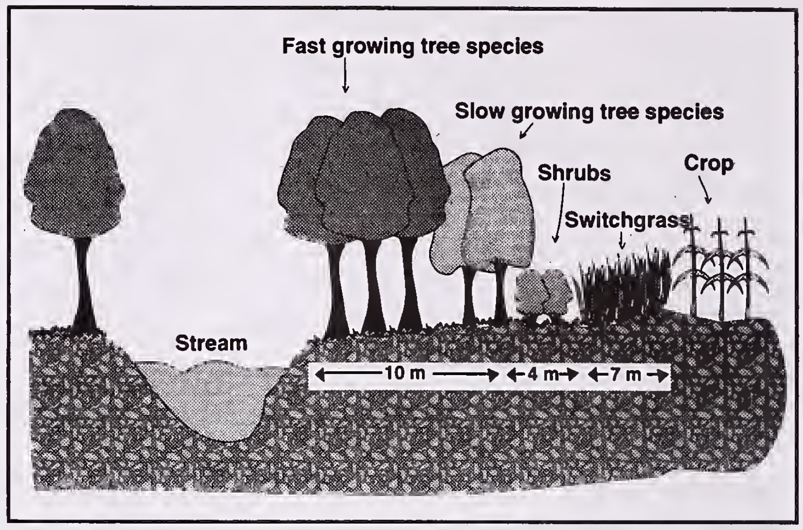

Figure 1 — The Leopold Center for Sustainable Agriculture, Agroecology Issue Team, Multi-Species Riparian Buffer Strip (MSRBS) Model. This model can be varied depending on site conditions, land-use practices, and owner objectives.

Multi-Species Riparian Buffer Strip (MSRBS) System

The Agroecology Issue Team (AIT) of the Leopold Center for Sustainable Agriculture located in Ames, Iowa and the Iowa State University Agroforestry Research Team (IStART) have developed multi-species riparian buffer strip (MSRBS) system for application in the Midwestern and Great Plains agroecosystem (Schultz et al. 1993, 1995). The MSRBS contains three zones similar to those of the FS and NRCS riparian forest buffer strip model. However, the widths and plant species compositions of the zones in the MSRBS model can be varied depending on landowner objectives, the upland land use patterns and the characteristics of the riparian zone. The MSRBS system is an integrated management system which also includes willow-post soil bioengineering features to stabilize streambanks and small, constructed wetlands, within the buffer strip. The wetlands are placed at the outlet of field drainage tiles to process agrichemicals contained in tile flow before it enters the stream. Figure 1 illustrates the three zone MSRBS model while Figure 2 illustrates the whole MSRBS system.

Beginning at the streambank edge, the first zone of the MSRBS is 10 m wide and contains 4-5 rows of rapidly growing trees, the second zone is 4 m wide and contains 1-2 rows of shrubs, and the third zone is a 7 m wide zone of native, warm-

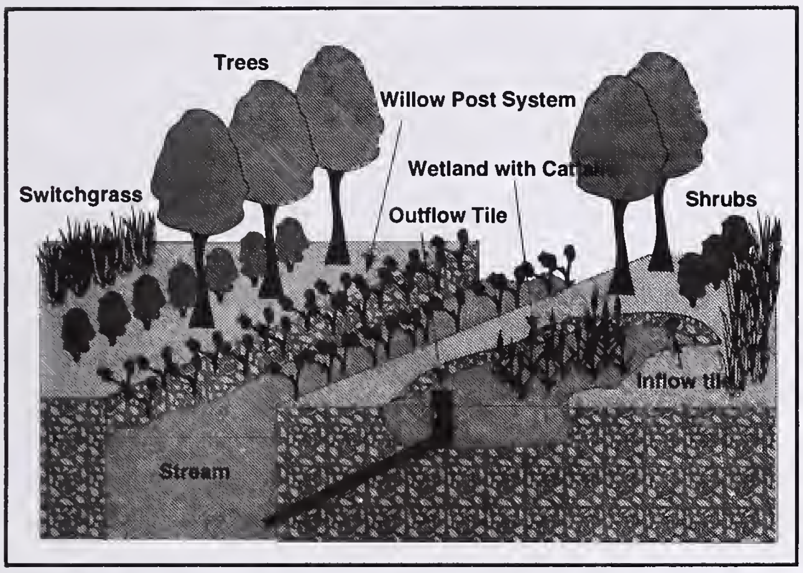

Figure 2 — The Leopold Center for Sustainable Agriculture, Agroecology Issue Team, Multi-Species Riparian Buffer Strip Model System which integrates the willow-post soil bioengineering system for streambank stabilization and constructed wetlands for reducing non-point source pollution in agricultural drainage tile flow.

season grasses. This zonation is important because the trees and shrubs provide perennial root systems and long-term nutrient storage close to the stream, while the shrubs add more woody stems near the ground to slow flood flows and provide a more diversified wildlife habitat. The native grasses provide the high density of stems needed to dissipate the energy of surface runoff and the deep and dense annual root systems needed to increase soil infiltration capacities and provide organic matter for large microbial populations.

Fast-growing trees are needed to develop a functioning MSRBS in the shortest possible time. It is especially important that rows 1-3 (the first row is the closest to the streambank edge) in the tree zone (zone 1) include fast-growing, riparian species such as willow (*Salix* spp) and cottonwood (*Populus* spp) species. If, throughout the year, the rooting zone along the streambank is more than 1.2 m above normal stream flow and soils are well drained, then upland deciduous and coniferous trees and shrub species can be planted in rows 4 and 5. Although these slower growing species will not begin to function as nutrient sinks as quickly as faster growing species, they will provide a higher quality product to the landowner at harvest. Shrubs are included in the design because their permanent roots help maintain soil stability, their multiple stems help slow flood flows and their presence adds biodiversity and wildlife habitat. Many native shrubs can be used and are often selected because of their desirable wildlife and aesthetic values.

As in the FS and NRCS forest buffer strip model, the native grasses function to intercept and dissipate the energy of surface runoff, trap sediment and agricultural chemicals in the surface runoff, and improve soil quality by increasing infiltration capacity and microbial activity as a result of their annually high turnover of roots. Native tall-prairie grasses are better suited to the MSRBS than the introduced cool season grasses that are usually used for grassed waterways because of their taller and stiffer stems and their more deeply distributed roots. The native grasses have 9 times greater root mass extending more than three times as deep as cool season grasses (Schultz et al. 1994, 1995). A minimum grass zone width of 7 m is recommended to dissipate the surface runoff, trap sediment, and promote significant infiltration.

The three zone MSRBS model of trees, shrubs, and prairie grasses is well suited to the agroecosystems of the Midwest and eastern Great Plains. Although these species combinations provide a very effective riparian buffer strip plant community, there are other combinations that can be effective. These might include combinations with more trees or shrubs or without any trees or shrubs, except for those used for streambank stabilization. The grass zone is the most critical of the three zones in the MSRBS. Site conditions, major buffer strip biological and physical functions, owner objectives, and cost-share program requirements should be considered in specifying species combinations.

Figures 3 and 4 show the dramatic changes that can take place in as little as four growing seasons after establishment of a MSRBS system located on the Risdal farm, along Bear Creek, near Roland, Iowa. This buffer strip has trapped 80-90 percent of the sediment carried in surface runoff and has reduced nitrate and atrazine agrichemical pollutants moving through the soil solution of the rooting zone or in the shallow ground water by over 90 percent, with resulting concentrations

Figure 3 — The Bear Creek MSRBS site near Roland, Iowa in March 1990. The land on the right hand side of the stream had been in cultivation and the land on the left hand side had been grazed. Notice the condition of the streambanks.

Figure 4 — The Bear Creek MSRBS site near Roland, Iowa in June 1994. Notice the rapid growth of riparian vegetation and the dramatic improvement in the condition of the streambanks after only five seasons since establishment of the MSRBS.

well below the maximum contaminant levels allowed by the US Environmental Protection Agency.

It costs about $875 per ha to install the three zone MSRBS. This includes plant purchases, site preparation, planting, labor, and maintenance costs in the first year. About $50 per ha should be planned for annual maintenance for the first 3-4 years.

Although the MSRBS model was developed to be 21 m wide on each side of a stream, different widths may be needed to fit specific sites and land ownerships. The total width of the buffer strip depends in large part on its major functions and the slope and use of the adjacent land. If the major purpose of the buffer strip is sediment removal from surface runoff, a width of 15 m may be sufficient on slopes of 0-5%. If excess nutrient removal also is an important function, a width of 15-30 m might be necessary depending on the kind and quantity of agricultural chemicals applied and the soil and cultivation system used.

As the slope, intensity of land use, or total area of the land producing NPS pollutants increases, or as soil permeability decreases, a wider MSRBS is required. Castelle et al. (1994) recommend buffer strips 10-60 m wide for sediment removal, 5-90 m wide for nutrient removal, 5-100 m wide for species diversity and 15-30 m wide for stream water temperature moderation. Welsch (1991) summarizes the work of others and suggests that buffer strip widths could be 20% of the total NPS pollutant area, or widths of land capability classes I, II, V = 29 m; III & IV = 36 m; VI & VII = 52 m. The FS riparian forest buffer model has a width of at least 29 m.

MSRBS Streambank Bioengineering and Tile Wetland Options

Streambanks that have been heavily grazed or that have had row crops planted to the edge of the bank are often very unstable and need extra protection beyond that provided by the MSRBS. In these situations soil bioengineering techniques, such as the willow post method, can be employed (Frazee and Roseboom 1993). On vertical or actively cutting streambanks, combinations of dormant willow 'posts' are planted along with anchored dead tree revetments to protect streambanks. These plant materials provide a frictional surface for absorbing stream energy, trapping sediment, and provide shade and organic matter for in-stream biota. Dormant willow posts (> 7.6 cm diameter and 2.1 m long), willow stakes (2.5-7.6 cm diameter and 0.5-1.8 m long) and willow cuttings (0.5-2.5 cm diameter and 30-45 cm long) are collected during the winter or very early spring. Rows of posts are driven into the streambank beginning at the waters' edge with spacing

between posts of 90-120 cm. Up to 4-5 more rows of posts, stakes, or cuttings are planted in parallel rows up the bank from the base row using 60-120 cm spacing within and between rows.

Where there is a concern for active undercutting of the bank, bundles of eastern red cedar or small hardwoods (3-4.5 m long silver maples, willows, etc.) can be tied together into 2-4 tree bundles. A row of these bundles is laid along the bottom most row of willow posts with the lower trunks pointed upstream and the bundles anchored to the willow posts or streambank.

In areas of artificial drainage, small wetlands can be constructed at the end of field tiles to interrupt and process NPS pollutants before they enter water bodies. A 0.5-1 m deep depression is constructed at the ratio of 1:100 (1 ha of wetland for 100 ha drainage). A berm should be constructed along the stream. It can be stabilized on the stream side with willow cuttings and seeded with a mixture of prairie grasses and forbs. If a coarse textured soil is encountered, the bottom of the wetland can be sealed with clay and topped with original soil. A gated control structure for controlling water level should be installed at the outflow into the stream. In designing the wetland it is important to remember that most of the chemical transformation and retention occurs at or near substrates (sediments or plant litter). Wetlands containing large amounts of vegetation and decaying plant litter will thus have a much greater capacity for pollutant removal. Any management technique which accelerates vegetation establishment (active regeneration) of litter buildup (addition of organic substrate) will improve chemical retention.

The willow-post soil bioengineering technique and the small field tile wetland are integral components of a complete riparian zone management system that effectively intercepts and treats NPS pollution. However, a MSRBS system cannot replace upland conservation practices. An agricultural landscape will be more sustainable if both upland conservation practices and a MSRBS system are in place.

Applying the MSRBS system at the landscape level becomes a real challenge because of ownership patterns and government set aside programs. Critical riparian areas in a watershed must be protected with riparian buffer strips. Farm boundaries typically are not based on watershed topography, and set-aside programs such as the Conservation Reserve Program encourage farmers to set aside whole fields rather than setting aside the same area of land as riparian buffer zones. Both voluntary or mandatory measures are needed to motivate landowners to install riparian buffer strips at the field level. At the landscape or watershed level, new or highly modified agricultural policies may be required to allow consumers and producers in areas without riparian zones to compensate producers who establish buffer strips and protect riparian zones for the loss of land necessary to meet watershed-wide soil conservation and water quality goals (National Research Council 1993).

Grazing Land Remediation

The semi-arid and arid western rangelands cover a wide latitudinal and elevational range with many potential plant communities so that prescription of the ideal grazing program for the riparian zone is difficult. In developing a grazing program for a given riparian zone several principles should be remembered (Chaney et al. 1993). First, grazing access to the riparian zone should be limited during those times when streambank soils are moist and most susceptible to compaction and collapse. This condition frequently exists during the early spring following snow melt and early spring rains. Second, enough plants and stubble or plant heights should be left on the streambank to ensure protection of the banks (Clary and Webster 1990). Stubble heights of 1.5-2.5 cm are often recommended. Third, grazing pressure should be controlled enough to allow desirable plants enough time to regrow and store enough carbohydrates for overwinter dormancy and competition with other undesirable species. Various seasonal strategies are available and will be discussed below.

Within any rangeland ecosystem the riparian zone will be most heavily used because of favorable forage, water, and microclimatic conditions.

Excluding livestock from the riparian zone is the simplest method of management. However, exclusion is often not necessary if intensity, duration, and season of grazing are controlled (Chaney et al. 1993; Elmore 1992). Using riparian pastures that are separate from upland pastures can control the grazing of the riparian vegetation but increase the complexity of management. The most complicated strategy is to attempt control of grazing intensity and timing through herding (Chaney et al. 1993).

Chaney et al. (1993), Elmore (1992) and Clary and Webster (1990) provide the following summary of grazing strategies for western riparian zones. Season-long or continuous grazing is the most detrimental unless it can be strictly controlled according to recommended stubble heights. With this scheme plants receive no rest for regrowth and carbohydrate storage for the dormant season. Woody plants are heavily impacted because constant browsing removes any new growth. This is the grazing practice which is most responsible for the deteriorated conditions of most of the riparian zones in both the cool and warm season grass ranges. Spring and summer grazing can be almost as damaging as season-long grazing because both cool- and warm-season grasses are grazed during their active growing and reproductive times. In addition, new growth on woody plants is severely browsed and livestock are present on streambank soils during wet periods. Spring and fall grazing has problems similar to those of spring and summer grazing.

Fall or winter grazing is a good strategy because plants are grazed when they are dormant and much of their food reserves are stored in tissues at or below ground level. To maintain a frictional surface for streambank protection it is important to adhere to a recommended stubble height of 1.5-2.5 cm. Browsing of woody plants often removes new growth from the past season requiring new growth from lateral or adventitious buds. One advantage is that cold air drainage often keeps livestock from concentrating along the stream. Care must be taken to reduce trampling during wet periods.

Early season grazing allows growth of plants the rest of the year while it puts pressure on upland plants during the summer and fall. In this system livestock should be removed while the plants are still in their vegetative growth stage and before they begin their vegetative growth. Woody plants benefit from this system because livestock graze on the lush herbaceous forage. Streambanks may be susceptible to compaction and trampling during this period but because of more available forage and less demand for water, livestock may be more dispersed over the whole range.

Deferred three pasture rotational grazing provides a rest period for each pasture every year. During the first year grazing occurs in spring, during the second it occurs in summer and during the third there is no grazing. This system is great for herbaceous plants but is detrimental to woody plants because they heavily grazed during two of the three years keeping them in a shrubby condition.

Two pasture rotational grazing provides growing season rest for each pasture every other year. During the first year grazing occurs in spring for cool season grasses or late spring-early summer for warm season grasses. The following year grazing occurs after vegetative growth has been completed, summer for cool season grasses and late summer-early fall for warm season species. This system is hard on any woody plant seedlings.

Chaney et al. (1993) suggest that no one system applies to all riparian locations and that any grazing strategy is only as good as it is managed. They further suggest that riparian exclosures and riparian pastures reduce the complexity of management and insure more rapid restoration of deteriorated riparian zones.

Summary

Because of the critical functions of riparian buffer systems in crop and rangelands across the US, development of riparian zone systems is a very important topic at the present time. To manage agricultural and rangeland landscapes for sustainable crop, forage, animal, and other non-market outputs means that NPS pollution must be controlled, water quality maintained at a high

level, and biodiversity enhanced. Sustainable agriculture also means diversifying the economic and environmental opportunities for the farmer or rancher as well as diversifying the landscape. The MSRBS system provides an opportunity to accomplish a combination of social, economic, environmental, and political objectives. To date most riparian zone research has been conducted either in existing naturally vegetated riparian zones or using cool-season grass buffer strips. Also, research has focused on either a buffer strip, a wetland, or streambank stabilization models. The MSRBS system is an integrated model. It takes a systems approach to the complex set of crop and rangeland riparian problems and economic and social issues facing farmers and ranchers. Adaptation is the rule rather than the exception with the MSRBS system.

It seems that a MSRBS system offers numerous additional advantages over the traditional cool season grass buffer strips and could be designed to be more efficient at trapping sediment and reducing agrichemicals than existing natural systems. Moreover, the MSRBS system is designed to diversify the agricultural landscape by introducing wildlife corridors with a variety of habitats along streams and provide for enhance aesthetics. The opportunity exists for farmers or ranchers to "sell" hunting rights associated with riparian zones where the MSRBS system has been developed. Market products such as hay from the warm-season grasses, fuelwood from the fast-growing trees, and sawlogs from slower-growing quality hardwood tree species can be produced by the MSRBS over time. In fact the removal of such "crops" enhances the functioning of the MSRBS. The MSRBS system offers a way to address the field tile problem whereby NPS pollution by-passes the living filter/ agrichemical transformation and sink functions of the vegetative (tree/shrub/grass) buffer strip. A constructed wetland is an important component of the MSRBS system. A relatively small constructed wetland can effectively treat the NPS pollution from agricultural land 100 times its size. Yet another important component of the MSRBS system are the streambank stabilization soil bioengineering techniques using willow or other vegetation to reduce bank slumping and storm scouring, and causing soil deposition among the woody stems and collected debris.

Livestock exclusion is the simplest approach to management of the rangeland riparian zones of the arid and semi-arid west. However, this approach excludes the most productive ecosystem from livestock use and may not be an option in narrow Midwestern riparian zone pastures. An alternative would be to manage the riparian corridors as pastures separate from the uplands. In that way grazing can be regulated by season, intensity and duration. Planting of multiple species of adapted plants can be done to improve forage production as well as to stabilize streambanks and create wildlife habitat.

There are still many unanswered questions about the design, function, and management of the MSRBS, constructed wetlands, streambank stabilization designs, or any other buffer strip designs. Among the most important are quantification of the sediment trapping ability and the nutrient and pesticide reduction ability of the buffer strips. Quantification of changes in soil and water quality and in-stream environment resulting from the presence of the permanent MSRBS system are also needed. Wildlife habitat values must be assessed and a careful accounting of all socio-economic and environmental benefits and costs of these systems must be made. However, riparian buffer strip systems provide a method of developing productive and sustainable crop and range landscapes in the Midwestern and Great Plains agroecosystems and the semi-arid and arid western rangelands.

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Soil Bioengineering: The Use of Dormant Woody Plantings for Slope Protection[1]

Gary W. Wells[2]

Abstract — The Soil Conservation Service uses the term soil bioengineering to describe the use of live, woody vegetative cuttings to repair slope failures and increase slope stability. The cuttings serve as the primary structural components, drains, and barriers to earth movement. Soil bioengineering combines mechanical, biological, and ecological concepts to create sustainable systems. The cuttings used are from easily rootable species, such as willow, and the collection or propagation of desirable species provide an agroforestry opportunity.

Introduction

The value of vegetation to reduce soil erosion has long been recognized. However, the value of woody vegetation to reinforce slopes and provide barriers to earth movement has been overlooked. The purpose of this paper is to introduce soil bioengineering techniques and their potential application for slope protection.

There are many terms being used that deal with the use of plant materials for engineering purposes. Biotechnical slope protection is used to describe the use of living vegetation with inert structural components to reinforce soil and stabilize slopes. Soil bioengineering differs in that it primarily uses live plants and plant parts for soil reinforcement and barriers to earth movement.

Soil bioengineering is an applied science that combines mechanical, biological and ecological concepts to create a living structure for slope stabilization. Adapted woody species are arranged in a specific configuration that provides immediate soil reinforcement. As the plants grow, the roots provide shear strength and resistance to sliding. When properly designed, soil bioengineering techniques not only help to stabilize slopes, they also improve infiltration, filter runoff, transpire excess moisture, moderate ground temperatures, improve habitat, and enhance aesthetics.

Soil bioengineering is a recent term, however the concepts date back to the sixteenth century in Europe. In the 1930's and 40's there were several professionals using and perfecting "living construction" techniques. The Soil Conservation Service (SCS) and the Forest Service were also evaluating soil bioengineering techniques during the 1930's. After World War II these techniques lost out to more conventional engineering solutions of concrete, rock, and steel. With the recent concern for environmental quality, interest in soil bioengineering techniques has increased.

Soil Bioengineering Techniques

There are numerous soil bioengineering techniques. They all utilize dormant cuttings of indigenous plant materials. Species that root easily from cuttings, such as willow and dogwood shrubs, are used and can be harvested from local sources. Soil bioengineering techniques include live staking, brush mattress, brushlayer, live

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[1]*Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10. 1994).*

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fascine, branchpacking, and post planting. There are also several techniques that can be used in combination with conventional engineering, these include live cribwalls, joint plantings, vegetated rock gabions, and vegetated geogrid. These techniques are used to design systems for both upland slope protection and streambank protection.

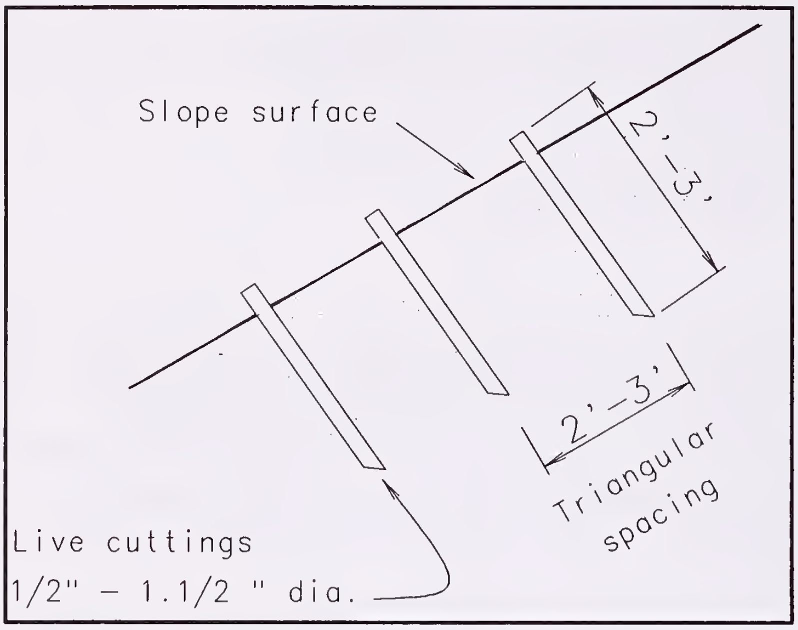

Figure 1 — Live Stakes

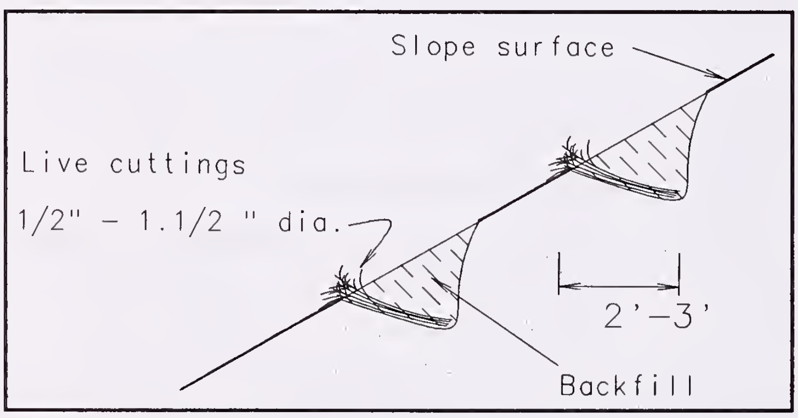

Figure 2 — Brushlayer

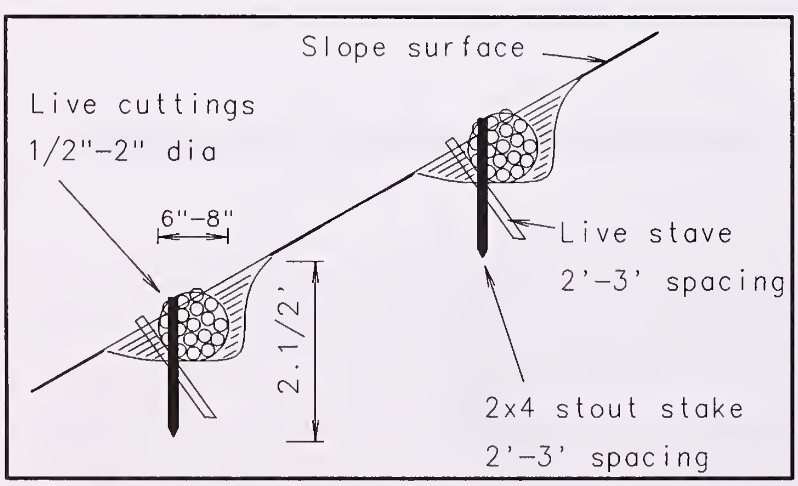

Figure 3 — Live Fascine

Live Stakes

Live staking (Figure 1) involves the insertion of a live, rootable vegetative cutting into the ground. Cuttings are 2 to 3 feet long and 1/2 to 1 1/2 inches in diameter. Stakes are pruned to be free of side branches with bark intact. They are installed basal end down the same day they are harvested. The stakes are placed 2 to 3 feet apart on a triangular spacing with only 1/5 of their length exposed. Stakes are either pounded in or an iron bar can be used to make a pilot hole in firmer soil.

Brushlayer

Brushlaying (Figure 2) consists of placing live branch cuttings in a trench perpendicular to the slope. A trench 2 to 3 feet wide is dug on the contour and 1/2 to 2 inch diameter cuttings are placed with the basal ends against the slope. The trench is then backfilled with soil and compacted slightly to eliminate air spaces.

Live Fascine

Live fascines (Figure 3) are long bundles of cuttings that are bound together in sausage-like structures. Long straight branches are used to form the 6 to 8 inch diameter bundles. The bundles are placed in a trench so that the top of the bundle is exposed after backfilling. Dead stout stakes cut from 2 by 4 lumber and used to secure the fascine. Live stakes are also placed on the downward side of the fascine.

Brushmattress

A brushmattress (Figure 4) utilizes 1 inch cuttings 6 to 9 feet long to cover a slope. Live stakes and live fascines are used to help secure the brush mattress. The basal ends of the cuttings are placed in a trench under the live fascine at the

base of the slope. Both live and dead stout stakes are placed on a 2 to 2 1/2 foot spacing. Number 10 smooth wire is stretched diagonally between stakes and wrapped 6 inches from the top of the stake. The stakes are then driven into the ground, tightly securing the brushmattress to the slope.

Branchpacking

Branchpacking (Figure 5) consists of alternating layers of live branch cuttings and compacted backfill to repair a small slump or gully. Dead stakes made from 2 by 2 lumber are driven 3 to 4 feet into the ground, 1 to 1 1/2 feet apart. A 4 to 6 inch layer of 1/2 to 2 inch diameter live branches are placed criss-cross between the stakes with the basal ends touching the slope. A 12 to 18 inch layer of soil is added and compacted. The process is repeated until the slump is filled.

Post Plantings

Post plantings (Figure 6) are used to form pervious revetments along streambanks. Posts are usually larger than 3 inches in diameter and 7 to 9 feet in length. Side branches are removed and the posts are placed in holes made from augers or rams to about half their length. Two or more rows of posts are placed 2 to 4 feet apart using a square or triangular spacing.

Joint Planting

Joint planting (Figure 7) involves the placing of live stakes in the joints of rock riprap. If the rock has been previously placed on the slope, a steel rod or other device is used to establish a hole in the joints of the rock. The stakes can also be placed as the rock is being placed on the slope.

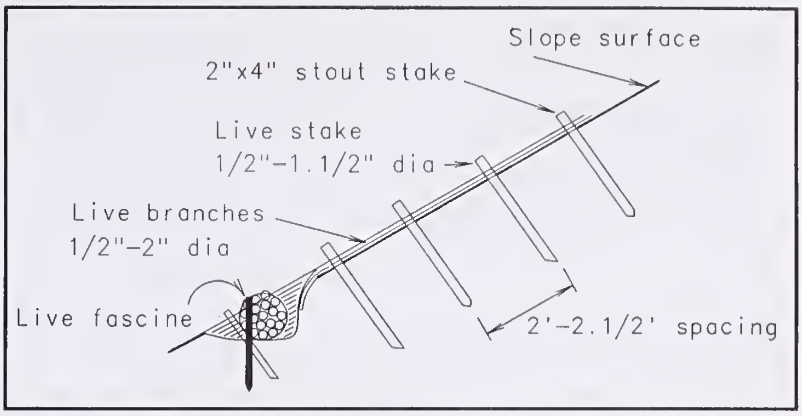

Figure 4 — Brushmattress

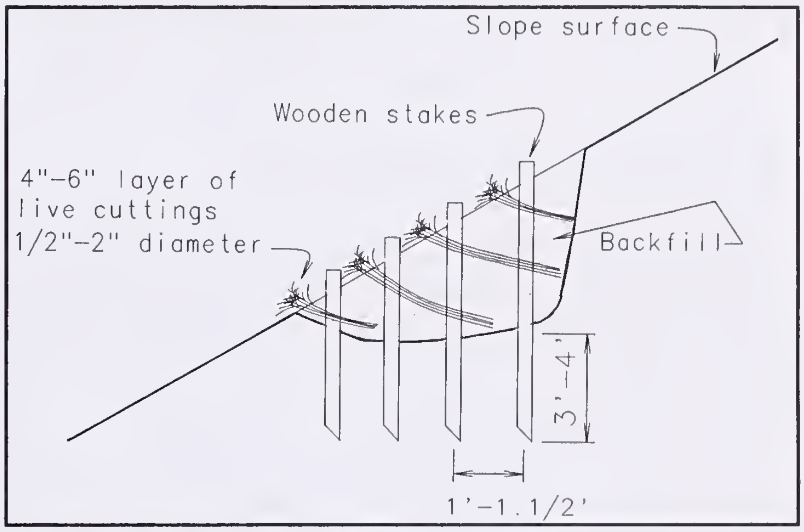

Figure 5 — Branchpacking

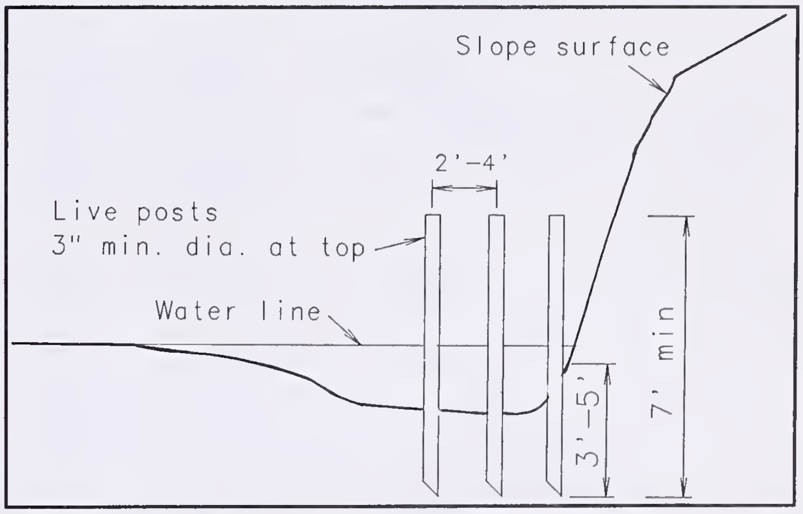

Figure 6 — Post Planting

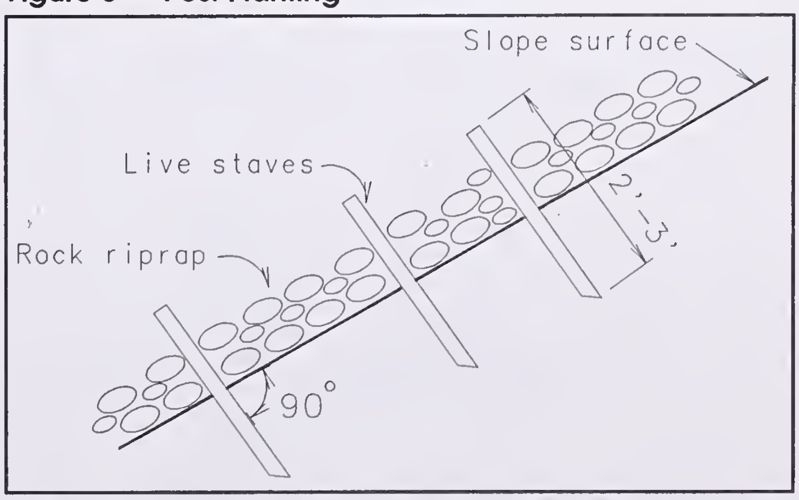

Figure 7 — Joint Planting

Live Cribwall

A live cribwall (Figure 8) combines a hollow, box-like interlocking wood structure and live cuttings. The untreated timber or logs are layered to form openings in the structure. Soil is placed in the crib and cuttings are placed in the openings as the layers are built up. The 1/2 to 1 1/2 inch diameter cuttings are placed perpendicular to the slope and protrude through the crib.

Vegetated Rock Gabions

Gabions (Figure 9) are wire baskets filled with stones. A series of gabion baskets are used to form a wall or stabilize a slope. Live branches are placed between each layer of gabion baskets to create a vegetated rock gabion. Cutting range from 1/2 to 1 inch in diameter and are cut long enough to reach into the undisturbed bank while protruding beyond the front of the gabion. Soil is also placed between the gabion layers.

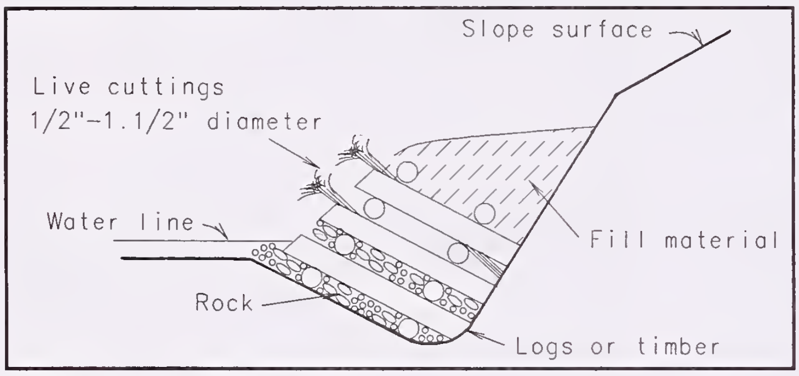

Figure 8 — Live Cribwalls

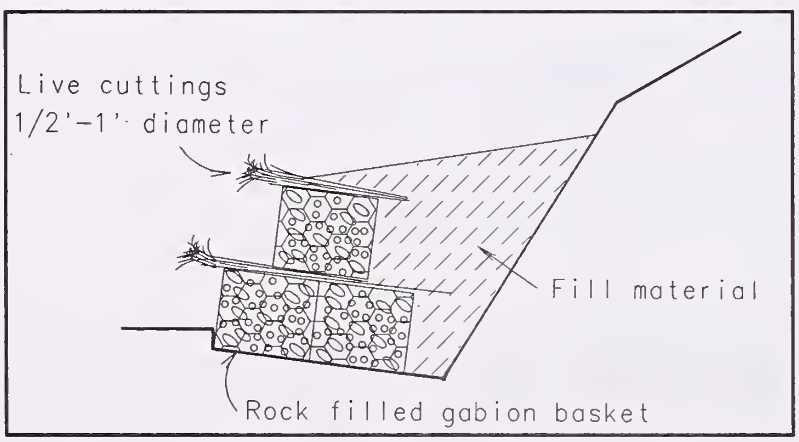

Figure 9 — Vegetated Rock Gabions

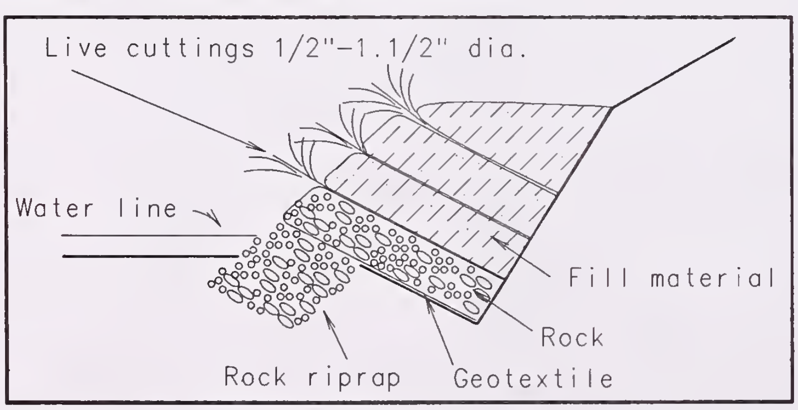

Figure 10 — Vegetated Geogrid

Vegetated Geogrid

Geogrids (Figure 10) utilize natural and synthetic geotextile materials to form steep slopes. Soil or stones are placed in layers formed by the geotextile material. Live cuttings 4 to 6 feet long and 1/2 to 1 inch in diameter are used between each layer.

Plant Materials

Soil Bioengineering requires woody species that root easily from cuttings. They must also be adaptable to the site conditions. Streambank situations may be inundated at times and upland sites may be droughty. Table 1 provides a general list of plant species used in soil bioengineering. As with any planting design, it is desirable to use a variety of species to minimize failure due to insects and disease.

Plants can be harvested from nearby native stands reducing transportation costs. Locally obtained materials are often collected at no charge, landowners usually welcome the clearing of willows. Since the plants are only topped, the harvest site quickly resprouts. Another alternative being evaluated by the SCS is the establishment of production beds for the harvesting of these materials. Several evaluations are underway to compare the differences between locally collected and production bed plant materials for soil bioengineering applications.

The growing of desirable soil bioengineering plant material in production beds provides a potential agroforestry market. As this technology gains in popularity there will be a need for large

Table 1 — Soil Bioengineering plant species

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Acer negundo Boxelder	N, NE	Common	Excellent	Small tree	Mod. deep spreading	Poor-fair
Alnus rubra Red alder	NW	Very common	Excellent	Large tree	Shallow spreading	Poor
Baccharis glutinosa Water wally	W	Common	Very good	Medium shrub	Fibrous	Good
Bacccarls halimifolia Eastem baccharis	S, SE	Common	Very poor	Small-med. shrub	Fibrous	Fair-Good
Baccharis pilularis Coyotebrush	W	Very common	Good	Medium shrub	Fibrous	Good
Baccharis viminea Mule fat	W	Very common	Very good	Medium shrub	Fibrous	Good
Betula papyrifera Paper birch	N, E, & W	Common	Good	Tree	Fibrous shallow	Poor
Betula pumila Low birch	N, E, & W	Common	Very good	Medium shrub	Fibrous	Poor
Cornus amomum Silky dogwood	N, SE	Very common	Very good	Small shrub	Shallow fibrous	Very good
Cornus racemosa Gray dogwood	NE	Common	Very good	Med-small shrub	Shallow	Good
Cornus rugosa Roundleaf dogwood	NE	Common	Very good	Med-small shrub	Shallow fibrous	Fair-good
Cornus sericea ssp. stolonifera Red osier dogwood	N, NE, & NW	Very common	Very good	Med-small shrub	Shallow	Very good
Crataegus Sp. Hawthorn	SE	Uncommon	Good	Sm. dense tree	Top root	Fair
Elaeagnus commutata Silverberry	N. Cent.	Very Common	Poor shrub	Medium	Shallow	Fair-good
Ligustrum sinense Chinese privet	S, SE	Common	Fair-good	Small-med. shrub	Shallow fibrous	Good
Lonicera involucrata Black twinberry	E	Common	Poor-fair	Small shrub	Shallow	Good
Physocarpus capitatus Pacific ninebark	NW, W	Common	Fair	Small	Fibrous	Good
Physocarpus opulifolius Common ninebark	NE	Common	Good	Med-high shrub	Shallow lateral	Fair-good

Table 1 — Soil Bioengineering plant species (continued)

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Populus angustifolia Arrowleaf cottonwood	W	Common	Good	Tree	Shallow	Very good
Populus balsamifera ssp. trichocarpa Black cottonwood	NW	Common	Good	Tree	Shallow fibrous	Very good
Populus deltoides Eastern cottonwood	MW, E	Very common	Good	Large tree	Shallow	Very good
Populus fremontii Fremont cottonwood	SW	Very common	Good	Tree	Shallow fibrous	Very good
Populus tremuloides Quaking aspen	NW	Very common	Good	Large tree	Shallow	Fair
Robinia pseudoacacia Black locust	NE	Common	Very poor	Tree	Shallow	Good
Rubus allegheniensis Allegheny blackberry	NE	Very common	Very good	Small shrub	Fibrous	Good
Rubus spectabilis Salmonberry	SW	Very common	Good	Small shrub	Fibrous	Fair-good
Rubus strigosus Red raspberry	N, NE, & W	Very common	Very good	Small shrub	Fibrous	Good
Salix exigua Coyote willow	NW	Fairly common	Good	Medium shrub	Shallow suckering	Good
ssp. interior Sandbar willow	N, SE	Common	Good	Large shrub	Shallow to deep	Fair-good
Salix amygdaloides Peachleaf willow	N, S	Common	Good	Very large shrub	Shallow to deep	Very good
Salix bonplandiana Pussy willow	W & MW	Very common	Good	Medium shrub	Fibrous	Very good
Salix eriocephala ssp. ligulifolia Erect willow	NW	Common	Good	Large shrub	Fibrous	Very good
Salix gooddingii Goodding willow	SW	Very common	Good	Large shrub Small tree	Shallow to deep	Excellent
Salix hookeriana Hooker willow	NW	Common	Good	Large	Fibrous dense	Very good
Salix humilis Prairie willow	N, NE	Very common	Good	Medium shrub	Fibrous	Good
Salix lasiolepis Arroya willow	W	Common	Good	Medium shrub	Fibrous	Very good

Table 1 — Soil Bioengineering plant species (continued)

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Salix lemmonii Lemmon willow	W	Common	Good	Medium shrub	Fibrous	Very good
Salix lucida Shining willow	N, NE	Very common	Good	Med-large shrub	Fibrous	Very good
ssp. lasiandra Pacific willow	NW	Very common	Good	Large shrub Small tree	Fibrous	Very good
Salix lutea Yellow willow	W	Very common	Good	Med-large shrub	Fibrous	Very good
Salix nigra Black willow	N, SE	Very common	Good	Large shrub Small tree	Shallow to deep	Excellent
Salix purpurea Streamco	N, S, E, & W	Very common	Very good	Medium shrub	Shallow	Very good
Salix scouleriana Scoulers willow	NE	Very common	Good	Large shrub Small tree	Shallow	Very good
Salix sitchensis Sitka willow	NW	Common	Good	Very large shrub	—-—	Very good
Salix X cotteti Bankers willow	N, S, E, & W	Uncommon	Good	Small shrub	Shallow	Very good
Salix discolor Red willow	N, NE	Very common	Good	Large shrub	Shallow	Very good
Sambucus cerulea Blueberry elderberry	W	Common	Very good	Medium shrub	Fibrous	Poor
Sambucus canadensis American elderberry	NE, SE	Very common	Very good	Medium shrub	Fibrous	Good
Sambucus racemosa Red elderberry	NW	Common	Good	Medium shrub	—-—	Good
ssp. pubens Scarlet elder	NE	Common	Very good	Medium shrub	Deep laterals	Fair-good
Spiraea alba Meadowsweet spirea	N, E	Common	Good	Small dense tree	Dense shallow lateral	Fair-good
Spiraea douglasii Douglas spirea	NW	Common	Fair	Dense shrub	Fibrous suckering	Good
Spiraea tomentosa Hardhack spirea	NE	Common	Good	Small shrub	Dense shallow	Fair
Symphoricarpos albus Snowberry	N, NW, & E	Common	Good	Small shrub	Shallow fibrous	Good

Table 1 — Soil Bioengineering plant species (continued)

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Viburnum alnifoliun Hubbiebush viburnum	NE	Fairly common	Good	Large shrub	Shallow fibrous	Good
Viburnum dentatum Arrowwood viburnum	E	Common	Good	Medium shrub	Shallow fibrous	Good
Viburnum lentago Nannyberry viburnum	S, SE	Fairly common	Good	Large shrub	Shallow	Fair-good

quantities of plant materials. Desired species can be collected and planted in beds for later harvesting. Some species may not be abundant locally and production beds can be used to ensure sufficient quantities. Most soil bioengineering techniques utilize small diameter cuttings that would allow the production beds to be harvested on 1 to 3 year cycles.

When using rootable cuttings it is critical that they be harvested during the dormant season, September to March in most regions. Cuttings should be planted immediately after harvesting to minimize desiccation. Cold storage has been used with some success to hold the material for later installation.

Conclusion

Soil bioengineering techniques can be used to develop sustainable systems for slope or streambank protection. As these techniques grow in popularity the need for large quantities of desirable plant materials will create an agroforestry opportunity.

Soil bioengineering applications require an on-site assessment to determine applicability. Soil, hydrology, geology, climate and other site conditions need to be analyzed to determine the appropriate techniques. Once designed, skilled installers are needed for construction, and the site should be monitored for survivability.

The Soil Conservation Service recognizes soil bioengineering techniques as a potential alternative in resource conservation planning, and technical guidelines are being developed. Initial efforts include Chapter 18 of the Engineering Field Handbook titled "Soil Bioengineering for Upland Slope Protection and Erosion Reduction". The agency is also evaluating several demonstration projects to gain information for the refinement of design guidelines.

Soil bioengineering will not replace conventional engineering solutions. There are many situations where soil bioengineering techniques are not appropriate. Where appropriate, soil bioengineering has proven to be cost effective and environmentally sensitive. Installations are labor intensive, but cost less than conventional engineering solutions.

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Windbreak Systems in the Western United States[1]

Bruce C. Wight and Lyn R. Townsend[2]

Abstract — How can windbreaks assist in achieving sustainability in agricultural systems? Windbreaks have traditionally been used to protect soil, plants, animals, and people from adverse winds. Wind erosion is a major concern for agricultural land in the West. Windbreaks have played a key role in reducing this threat in the West with approximately 80 percent of the field windbreaks in the United States occurring there. Modification of the wind with accompanying changes in the microclimate including temperature, soil moisture, and humidity also leads to enhancements in plant and animal growth. By protecting the soil resource and enhancing plant and animal growth, windbreaks have helped sustain agricultural systems in the West for the past fifty years or more. However, there are several future challenges for windbreaks. When the number of windbreaks applied is compared to the potential number, a large task still remains. The age and condition of existing windbreaks also raises a big concern for the future. Finally, are there more uses of windbreaks that need to be explored such as providing alternative products like fruit, nuts, floriculture, wood products, etc.? Windbreaks may be one of the oldest and most widely used agroforestry practices in the West, but there is still much that can be done.

Introduction

Windbreaks have been a key agroforestry practice in the West for the past 100 years and continues to be the most widely used agroforestry practice. The objectives of this paper include:

1. Describing the main windbreak practices,
2. Explaining the benefits windbreaks provide,
3. Reviewing the current status of windbreaks in the West,
4. Exploring the future potential of windbreaks.

The USDA Soil Conservation Service (SCS) has recently revised their national windbreak standard. The following is the new definition:

- Windbreak/Shelterbelt Establishment: Linear plantings of trees or shrubs established for environmental purposes (SCS, 1994).

The environmental purposes referenced in the definition include the following (SCS,1994):

1. Reduce wind erosion
2. Protect growing plants
3. Manage snow
4. Provide shelter for structures and livestock
5. Provide wildlife habitat
6. Provide a tree or shrub product
7. Provide living screens
8. Improve aesthetics
9. Improve irrigation efficiency

The focus of this discussion will be on three types of windbreaks:

1. Farmstead windbreaks
2. Field windbreaks
3. Livestock windbreaks

Other papers in the proceedings will discuss more detail about snow management and wildlife.

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[1]Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).

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Farmstead Windbreaks

When windbreaks are discussed with many landowners, the value of farmstead windbreaks is generally recognized. In fact, that is usually the first windbreak planting opportunity for most farmers and ranchers. A farmstead windbreak provides a number of benefits to the owner. Some of these benefits can be easily translated into dollars but others are more difficult. The benefits are shown in Table 1 (Wight, 1988).

The energy savings of 10 to 40% for the home and other buildings results primarily from reduced heat losses from air infiltration (DeWalle and Heisler, 1988). The further north the larger the savings. The better built the home the lower the savings due to lower air infiltration from better insulation and tighter openings. Windbreaks can prevent problem snow drifts around buildings. The snow removal cost savings will vary from year to year but can be substantial. Additional protection is also provided to buildings and equipment from wind damage and to humans who have to work outside throughout the year.

A well established windbreak can also increase the property value. A rural subdivision in North Dakota established windbreaks prior to selling the lots for homes. The lots were sold for several thousand dollars more than similar lots without trees (Wight, 1987). A farmstead windbreak can also reduce noise from adjoining highways or other noise sources like grain drying equipment. Reductions of 10 to 20 decibels of noise can be achieved with well designed plantings (Cook and Van Haverbeke, 1971).

Table 1 — Benefits of farmstead windbreaks

Benefit	Percent Change +/-
Energy Conservation	+10 to +40
Property Value	+6 to +12
Noise Attenuation	-10 to -20
Snow Removal	Variable
Working Conditions	Variable
Equipment Maintenance	Variable
Structure Maintenance	Variable
Road Dust	Variable

Table 2 — Benefits of field windbreaks

Benefit	Percent Change +/-
Crop Production	+6 to +44
Wind Erosion	-50 to -100
Snow Distribution	> +50
Irrigation	Variable

Field Windbreaks

The second windbreak practice is field windbreaks. Plantings of trees and/or shrubs adjacent to fields can provide wind protection and other microclimatic changes to adjacent fields resulting in improved crop quality and quantity. They can also serve as buffer strips to help improve water quality and add wildlife habitat. Field windbreaks provide a variety of benefits to adjoining fields and crops. See Table 2.

Ask most farmers to describe a field windbreak and they will often describe a large, multiple-row windbreak similar to those planted from 1935 to 1955. Today's field windbreaks are normally narrow windbreaks. These windbreaks often have only a single row of trees or shrubs and usually no more than two rows. Most of the benefits are a direct result of the changes in the microclimate on the leeward side of the windbreak. Studies have been done on a number of crops and in many areas to determine the influence on crop production. Field windbreaks have been shown to improve crop yields for corn, soybeans, spring wheat, and sunflowers in the United States and Canada and grain sorghum and winter wheat throughout the world (Kort, 1988). Yields are also improved in horticultural crops like fruit orchards and a variety of vegetable crops like onions which Dr. Brandle addresses in his paper in these proceedings. Windbreaks can also improve honey production by providing a calm area for the bees.

Do the yield increases in the protected zone make up for the losses due to plant competition and the land planted to trees? Generally the increase in yield will offset the depressed yield adjacent to the windbreak and from the land taken out of production by the windbreak. Depending on the crop grown, four to ten percent

of a field can be planted to windbreaks and still show an economic return (Brandle et al., 1992). The yield response can be generalized in a curve (Brandle and Hintz, 1987). See Figure 1.

Yield benefits extend from 10 to 15 H to the leeward of a field windbreak and 2 to 5 H to the windward. In fact, a summary of yields of major crops from around the world indicates a significant increase for the major crops planted in the Western United States. The degree of increase will vary from year to year depending on weather conditions. Table 3 was developed by Kort (1988) after reviewing current literature from around the world.

Using field windbreaks to reduce wind erosion has multiple benefits. Field windbreaks can protect young crop seedlings from soil abrasion during wind erosion events resulting in less need for replanting. Studies also show that plants unprotected from wind can result in reduced growth rate and lower plant quality (Grace, 1988). By reducing wind erosion, windbreaks help maintain the soil productivity of the field and reduce the offsite damages to waterways, adjoining crops, roads, and buildings from the blowing soil.

Table 3 — Crop response to shelter

Relative responsiveness of various crops to shelter

Crop	No. of field years	Weighted mean yield increase (%)
Spring wheat	190	8
Winter wheat	131	23
Barley	30	25
Oats	48	6
Rye	39	19
Millet	18	44
Corn	209	12
Alfalfa	3	99
Hay (mixed grasses and legumes)	14	20

Field windbreaks are also effective tools for managing moisture in the semi-arid regions of the West. Managing snow to provide additional moisture for crops is one way to improve moisture efficiency with field windbreak systems. This is especially important in areas where snow provides a significant proportion of the available moisture. Care must be taken in the design of

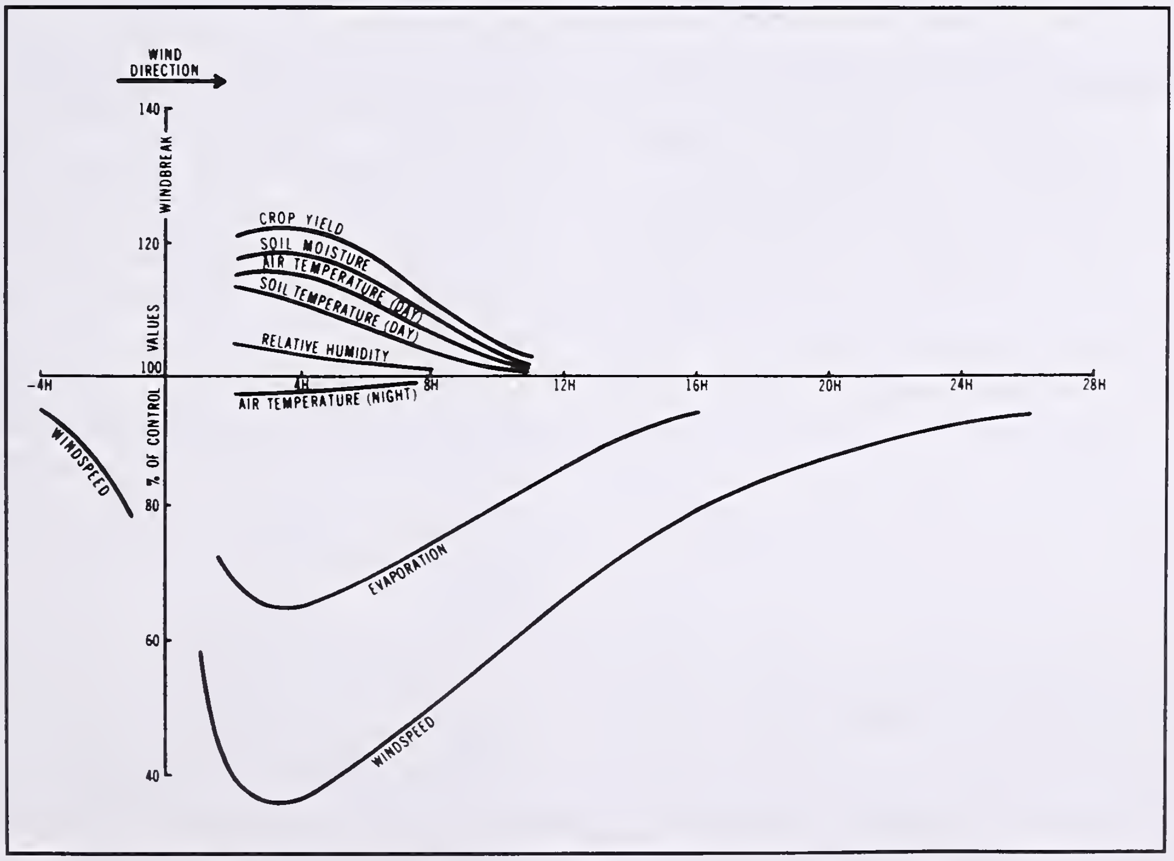

Figure 1 — Generalized changes in crop yield and environmental factors with distance from a windbreak. The vertical axis, located at the windbreak under conditions where snow is important, The vertical axis located at the windbreak, gives values of the yield and environmental factors as percentages of the values in open fields with no windbreaks. The H units on the horizontal axis are multiples of the height of the windbreak (l).

snow management windbreaks since the size and location of the snow drift is a function of windbreak density (Scholten, 1988). Caution must be used when lowering the density of the windbreak for snow distribution, and wind erosion protection is also desired. If the density is reduced too much, the effectiveness of the windbreak for wind erosion is lost.

Snow can be spread evenly across the field with not only tree and/or shrub windbreaks but also herbaceous barriers. A tree and shrub windbreak system can be supplemented with herbaceous barriers like tall wheatgrass (Agropyron elongatum L.) or switchgrass (Panicum virgatum L.) or can be composed entirely of grass barriers. Herbaceous barriers can be a very effective means of harvesting snow (Black and Aase, 1988).

Field windbreaks can improve the distribution and utilization of irrigation water (Dickey, 1988). With reduced wind speeds, less water can be lost to evapotranspiration. The crop uses the available water more efficiently and reduces the chance for excess irrigation in some fields which may have an impact on pumping costs.

Alley cropping is similar to field windbreak layouts with single rows of trees or shrubs planted at varying widths with crops grown in the "alleys" between the tree rows. The major difference with field windbreaks is that the rows of trees or shrubs are planted with the intention of obtaining a product in the future such as wood or nuts instead of just protecting the crop. Some of the benefits of alley cropping include:

1. Reduce water and wind erosion
2. Improve crop production
3. Supplement income
4. Provide wildlife habitat and travel corridors
5. Improve aesthetic diversity

Livestock Windbreaks

Windbreaks also have a significant role to play in protection of livestock. The benefits of livestock windbreaks are shown in Table 4.

Windbreaks improve animal health, increase feed efficiency, and improve survivability during stress periods such as winter and spring storms.

Table 4 —Benefits of livestock windbreaks

Benefit	Percent Change +/-
Feed	-10 to -30
Livestock Mortality	Variable

All animals increase food intake and energy expenditure when subjected to temperatures below their comfort zone. For example, the estimated lower critical temperatures for beef cattle are:

- Summer coat or wet 59° F
- Fall coat 45° F
- Winter coat 32° F
- Heavy winter coat 18° F

Each degree below this critical temperature is considered a degree of cold. Increased maintenance energy costs occur for varying sizes and coats of beef cattle. For example, a 660 pound beef animal with a winter coat will need approximately 1.1 percent more feed for each degree of temperature (cold) below 32° F (Hintz, 1983).

Wind chills contribute to this impact on livestock energy needs. Windbreaks can reduce this impact by lowering wind velocities by as much as 70 percent. For a beef animal with a winter coat, a 20° F. temperature with a 20 miles per hour (mph) wind feels like 0° F. temperature without a windbreak and 13° F. with a windbreak (Hintz, 1983).

Let's look at an example of the amount of energy demand on a 660 pound beef animal with a winter coat. The air temperature is 20° F. and the critical temperature is 32° F. For a 20 mph wind the wind chill on this animal will be 0° F. in the open and 13° F. behind a windbreak. When these two wind chills are subtracted from the 32° F. critical temperature, the degrees cold can be determined:

- 32° - 0° = 32 degrees cold in the open
- 32° - 13° = 19 degrees cold behind a windbreak

The degrees cold are then multiplied by the percent increase in energy cost for each degree cold. In this case it is 1.1 percent:

- 32 degrees cold (in open) x 1.1% = 35% increased energy need
- 19 degrees cold (with windbreak) x 1.1% = 21% increased energy need

In this situation the windbreak provides a 14% savings in energy needs of the beef animal. This translates into less feed demands or less weight loss. These savings are greatest for confined livestock, but windbreaks are also important for cattle or other livestock on the open range. These livestock windbreaks are often referred to as living barns. Living barns can mean the difference between life and death for animals caught in a storm.

Windbreaks as a Resource

Agroforestry proponents may recognize the benefits of windbreaks but how many windbreak systems have been applied to achieve these benefits and help improve sustainability? According to the 1987 SCS National Resources Inventory (NRI) (SCS, 1990), windbreaks comprise a substantial resource. See Table 5.

A significant number of these windbreaks occur in the seventeen western states as shown in Table 6.

About two thirds of the individual windbreaks occur in the West, but about three fourths of the area and length of windbreaks are in the West indicating that western windbreaks are generally larger. Tables 7 and 8 indicate the distribution of farmstead and field windbreaks and the trend from 1982 to 1987 for five regions in the West and the United States.

Table 5 — National total of farmstead and field windbreaks from the 1987 National Resources Inventory.

Windbreaks	Number	Acres	Miles
Farmstead	508,485	766,329	59,540
Field	349,672	599,116	116,031
Total	858,157	1,365,445	175,571

Table 6 — Percentage of farmstead and field windbreaks in the seventeen western states from the 1987 National Resource Inventory.

Windbreaks	Number	Acres	Miles
Farmstead	59	71	68
Field	74	82	80
Total	65	76	76

Table 7 — Regional and national trends for farmstead windbreaks.

	Acres		
Region	1982	1987	% Change
Northern Great Plains	494,925	487,825	-1
Southern Great Plains	37,140	30,054	-5
Southwestern	3,314	3,281	-1
Intermountain	19,033	19,146	+1
Pacific Northwest	803	773	-4
West Total	**555,215**	**546,079**	**-2**
United States Total	**779,660**	**766,329**	**-2**

Table 8 — Regional and national trends for field windbreaks.

	Miles		
Region	1982	1987	% Change
Northern Great Plains	69,467	68,063	-2
Southern Great Plains	22,595	21,499	-5
Southwestern	2,182	2,162	-1
Intermountain	1,559	1,498	-3
Pacific Northwest	410	433	+6
West Total	**96,213**	**93,655**	**-3**
United States Total	**120,612**	**116,031**	**-4**

As expected the Great Plains has the majority of the windbreaks. From 1982-1987 we have seen a small decline in windbreak amount. In looking at the changes from 1982-87, it is apparent that the Southern Great Plains has experienced the most loss in both farmstead and field windbreaks. When the 1992 NRI windbreak data is released in the near future, the next five year trend will be examined.

The past data has only given a quantitative look at the windbreak resource. In the 1992 NRI, a subsample was completed in four states, Kansas, Nebraska, North Dakota, and South Dakota, to look at the quality of the windbreaks in those states. As a person travels across the country, indicators of declining windbreaks can be spotted. Some are subtle such as placement of a snow fence inside a windbreak. Others are more obvious like dead or dying trees in windbreaks and the most obvious are piles of dead trees removed from a field. But just how large is the

renovation need? If this subsample is any indication, it is large. The following are the preliminary findings for Kansas and South Dakota. The data shown are only percentages of the sampled windbreaks and not statistical projections for the entire resource. Over 40% of Kansas windbreaks are greater than 40 years old. Contrasted with the South Dakota windbreaks which are somewhat younger. Roughly half of the windbreaks sampled in Kansas were in fair to poor condition. In South Dakota, although the windbreaks were younger, nearly two thirds were in fair to poor condition. In Kansas, about two thirds of the windbreaks needed some type of renovation. In South Dakota however, over 80% need some type of renovation. These figures would indicate that to maintain our existing windbreak resource expanded emphasis must be placed on management. At the same time, a look at the land without any windbreak protection, demonstrates a large potential for expanded plantings. However, the dead and dying windbreaks may be providing obstacles to expansion due to the current attitude of landowners with windbreak renovation needs.

In conclusion, agroforestry, specifically windbreaks, can be the answer to:

- Biodiverse habitats for humans and wildlife.-
- Enhancement of local ecosystems.
- Reduction of resource problems and costs.
- Increase in "profits" for clients and society.

With increased interest and help by landowners and resource professionals, landscapes with few trees and diversity can be transformed into multiple species and practices that can enhance the farms, families, and future of the West.

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Living Snowfence: Friend or Foe[1]

Daniel J. Perko[2]

Abstract —Windblown snow creates problems for rural landowners, livestock, wildlife, and small rural communities. Snowdrifts block transportation routes, cost taxpayers to plow roads, cause safety concerns for travelers, and increase livestock and wildlife mortality. Properly designed and maintained living snow fences can diminish these problems and harvest moisture from the captured snow.

Introduction

Blowing snow and the resultant drifts forever created problems for man inhabitating the High Plains. Early westward settlers left St. Joseph, Missouri in early spring to reach their destinations before winter's deep mountain snow and blizzards on the plains. Although modern man has progressed to develop high-speed engineered transportation routes, sophisticated weather predicting radar with computer models, and powerful snow blowing and plowing equipment, winter blizzards and snow drifts still rule the winter.

In many locations small segments of roadways, subject to drifting, cause miles of highway to be closed for motorist safety. Numerous structures have been designed to control the blowing snow and minimize plowing operations. Costs have often prevented these structures from being installed. One example is the Wyoming Design board snow fence. At 13.8 feet in height, this barrier can be seen along hundreds of miles of Wyoming highways. With installed costs of nearly $57,000 per mile and an average annual maintenance cost of $1,320 per mile it is not inexpensive (Wyoming Department of Transportation, 1992).

Railroad companies as early as 1905 planted living barriers to control blowing snow along rights-of-way. By 1915 the Great Northern Railway Company reported one-half million seedlings in the ground. Other railway companies and some highway departments followed suit. But the droughts from 1929-33 caused severe mortality to many plantings. Planting ceased because soils and climate of the high plains were thought not suitable for planting without expensive maintenance. Over 50 years passed before the concept of living snow fences was reborn in Nebraska. Since then many states have initiated living snow fence programs.

Winter snow accounts for 50 percent or more of annual precipitation in many areas. In Cheyenne, Wyoming the average annual precipitation is 14.4 inches according to the National Weather Service. Average snowfall is 52.1 inches and accounts for over five inches of precipitation. Blowing snow not captured in drifts continues to be moved by the wind until it sublimates, usually within 3,300 feet (Tabler and Schmidt 1971). Neither soil moisture or water are realized in this process. Loss of this portion of annual precipitation would transform Cheyenne from a semiarid to desert region.

Key Elements

Key elements of living snow fence design affecting drifting are height, density and length.

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Independently they contribute to the function of the barrier, in combination they make up the design and fulfill the specific purpose of a living snow fence and associated multiple benefits.

Height

The height of the barrier is determined by the tallest row in a planting. Barrier height affects snowdrift depth and length. Species selected for a living snow fence in conjunction with soils in the planting area will determine barrier height.

Snow storage potential can be manipulated by barrier height. By doubling height snow storage is increased by four times, an important economic fact to consider in species selection. Example: one row of caragana (*Caragana arborescens*) with a mature height of 10 feet, can store the same amount of snow as four properly spaced rows of cotoneaster (*Cotoneaster acutifolia*), with a mature height of five feet, with all other factors being equal.

Density

Barrier density is determined by the species, number of rows, spacing between rows, and spacing of plants in the row. It is important to consider winter density since density of deciduous species vary by season. Density affects both windward and leeward drift lengths and heights.

Although research on living barriers is limited, information on constructed barriers indicates a 50 percent dense barrier stores the greatest amount of snow if other factors are equal (Tabler 1988). Wyoming research shows barriers with densities ranging from 77 to 92 percent cast leeward snow drifts averaging nine times barrier height. A barrier with 64 percent density casts an average leeward snowdrift of 12H, and at 50 percent density the drift averaged 25-30H (Peterson and Schmidt 1984).

Figure 1 indicates drifts formed windward of solid (100 percent) barriers extend upwind 10 to 12 times height at equilibrium and have a maximum depth equal to the barrier height. Windward drifts formed with 50 percent dense barriers extend upwind to 15 times height and have a maximum depth equal to 1/2 the barrier height (Tabler 1988).

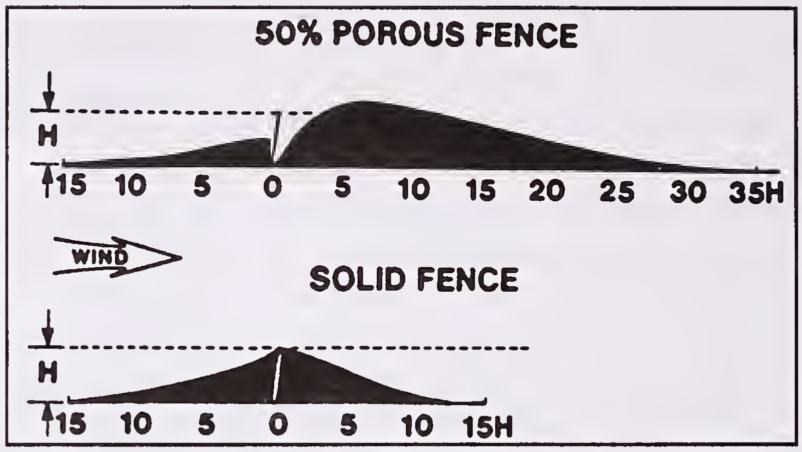

Figure 1 — Drift profiles with porous and solid barriers. From "Snow Control Course Notes" by R.D. Tabler (1988).

Barrier density combined with height are most important when determining the placement of the living snow fence in relation to its distance from the road or area being protected. The living snow fence should be placed as close to the road as possible yet far enough away so that the leeward drift edge does not reach the road.

Length

Barrier length determines the maximum length of area that can be protected if winds are perpendicular to it. However, snow storage at the ends of a barrier is significantly less than near the center. The end effect is due to wind turbulence or eddies generated at the fence end. End effect is caused by an acceleration of converging air flow to lateral pressure gradients developed downwind of the barrier (Tabler 1973).

If winds remain perpendicular to the barrier the resultant drift pattern, as viewed from above, will look like a blunted triangle with rounded edges. The subsequent rounding may extend inward toward the barrier center for up to 12H. In order to provide snow protection to an area, the barrier must extend at least 100 feet beyond each end of the area. In areas with nearly flat topography, it is recommended that the minimum barrier length be 30H (Tabler 1988).

With these numbers in mind, realistically, winds will not always be from exactly one direction. Barrier design must extend far enough beyond the protected area to intercept winds that deviate 25 degrees from either direction of perpendicular. Local conditions may necessitate an increase in the recommended 100 foot minimum. The recommended minimum barrier length helps compensate for loss of protection due to end effects. Another option is to design an "L", "C" or "U" shaped planting to account for greater variations in wind direction.

Barriers with an opening or gap at ground level allow snow to be blown through the barrier. A bottom gap of 10 to 15 percent of H causes a greater proportion of the blowing snow to be stored in the leeward instead of the windward drift. This causes the leeward drift length to increase and thus enhances storage capacity (Tabler and Schmidt 1986).

In order for a barrier to store snow in the smallest area possible, a bottom gap is not recommended. A dense barrier with no bottom gap can be located closer to the protected area or road. Snow is stored both up and down wind of the barrier and downwind drift length is minimized.

Design

In designing a living snow fence many site factors must be considered along with planting objectives and number and spacing between and within rows. Planting objectives may be as simple as snow control, or include livestock or wildlife protection or habitat, and/or water harvest and storage. Landowners may request aesthetic qualities in the form of spring flower or fall foliage colors.

Site factors considered include average snow volume to be stored; topography; soil type; distance upwind available for planting; soils, including type, fertility and PH; species suitability, longevity and resistance to snow breakage; and current and potential future land uses.

To maximize snow storage and minimize breakage, spacing between rows should be five to seven H. The windward drift of the downwind row will build back to the leeward drift of the upwind row as it tapers off. Closer spaced rows will only add to snow storage an amount equal to the space between the rows. One reason to plant rows closer would be to insure closure and maximize density of the barrier. Any planting design can be used which meets the planting objectives.

If a wildlife component is part of the planting objective be sure to plant food plots or cover in the protected area free of drifting potential. In severe winter storms other areas, including within the living snow fence, will be filled with drifted snow and have no wildlife values.

Water Harvest

Research to harvest snow for water has been conducted by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station using structural barriers. Similar application of techniques using living snow fence can be used. Problems were encountered when snow melt runoff infiltrated the ground before its capture. Techniques were explored to minimize infiltration. Designs around stock water dams were also tested to deposit snow into the pond area. For additional information on this research refer to the following publications:

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Conclusion

Blowing snow continues to be a problem in rural areas and on state and county roads. Structural and living tree and shrub barriers are being used in many states to reduce plowing operations. Snow fences reduce drifting on small segments of roadways which allows miles of roads to remain open. Key elements of living snow fence design are height, density and length. Height defines the downwind distance protected when combined with density. Density determines the upwind and downwind distance snow drifts are cast. Barrier length must be sufficient to provide protection to an area with wind deviations of 25 degrees in either direction. Other benefits, including wildlife habitat and water harvesting, can be derived from properly designed living snow fences.

Terms and Definitions

- **Density —** The ratio of solid area to total frontal area of the barrier.
- **End effect —** Loss of snow storage near the end of a barrier due to rounding and shortening at the ends of a drift. It is caused by generation of turbulent eddies at the barrier boundary and increases down wind from the barrier.
- **Equilibrium** — Sometimes referred to as capacity. When the barrier is at its full storage potential; saturated.
- **Fetch distance —** Distance upwind that is contributing relocated snow to a given location.
- **Height or H —** Height of the barrier or tallest row of vegetation. Height affects the amount of snow stored and area protected.
- **Maximum transport distance —** The greatest distance a windblown snowflake can travel before it evaporates. The distance is determined by the evaporation rate and can be less or greater than the fetch distance.
- **Storage capacity —** The maximum amount of relocated snow a barrier can capture and store.

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Trees and Pastures: 40 Years of Agrosilvopastoral Experience in Western Oregon[1]

Steven H. Sharrow and Richard A. Fletcher[2]

Abstract — Agroforestry research in western Oregon hill lands began as a joint effort of the Agriculture and Forestry faculties at Oregon State University in 1952 and continues today. Silvopastoral agroforestry presents opportunities to sustainably increase land productivity, improve cash flow, and to increase the diversity of plants and animals present on western Oregon hill lands. Agroforestry has yet to become widespread in western Oregon. However, agroforestry in western Oregon is now sufficiently developed that economically, biologically, and socially sound production systems have been designed and implemented by a core of early innovators. Awareness of agroforestry solutions to agricultural and silvicultural problems is slowly growing among local land owners. The relatively high profitability and social acceptability of well designed agroforestry systems ensure them a bright future in western Oregon.

Introduction

Agroforestry refers to the joint production of forest and agricultural products by actively managing the interactions between forest and agricultural plants and animals. Forestry and agriculture are the pillars of Oregon's natural resource based economy. Livestock production is the largest single component within Oregon agriculture. Therefore, it is natural that Oregon agroforestry emphasizes forest/livestock systems. Agroforestry in Oregon takes many diverse forms including grazing of native understory vegetation in young commercial forests and woodlots, tree/livestock production in forested rangelands, and livestock/timber production in thinned, mid-rotation forests. Trees planted into high producing, improved pastures on non-irrigated hill lands in the Willamette Valley and southwestern Oregon is our most intensely managed agroforestry system.

[1]*Paper presented at Agroforestry and Sustainable Systems Symposium, Fort Collins, Colorado, August 7-10, 1994.*

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There are approximately 1 million hectares of hill land in western Oregon. Much of this land historically supported oak *(Quercus garryana)* woodlands and savannahs. Hill lands are seldom used as croplands because of their steep slopes and shallow soils. Livestock grazing is the primary agricultural use. The original inhabitants of western Oregon were active land managers who used fire as a tool to produce grassy meadows and to keep oak woodlands open and parklike. Fire suppression in the last 150 years has supported a successional process by which hardwood trees have invaded previously open grasslands and formerly open hardwood forests have become closed canopy forests. Conifers, primarily Douglas-fir *(Pseudotusga menziesii)*, grand fir *(Abies grandis)*, and ponderosa pine *(Pinus Ponderosa)* are now beginning to break through the canopy of hardwoods in many areas. Apparently, many hill lands will support conifer forests, but trees may be difficult to establish, and growth rates are relatively slow compared to other commercial forest sites in western Oregon.

Agroforestry may present opportunities to increase land productivity by producing both trees and pasture/livestock products, to increase the diversity of plants and animals present , and

to improve cash flow by combining immediate income from grazing with later income from sale of trees. Because agroforestry systems tend to be self-sustaining, they may require little pesticide or fertilizer use. They are often park-like in appearance, and social acceptability is higher than traditional forest plantations. Social acceptability is becoming a significant issue because many hill lands are near urban centers, so land use must be especially sensitive to environmental quality issues including environmental contamination, destruction of native plant or animal habitat, and visual appeal.

Agroforestry research in western Oregon hill lands began as a joint effort of Agricultural, Forestry , and Agricultural Extension faculty at Oregon State University in 1952 (Hall et al. 1959) and continues today. To date, five experimental agroforests have been established and over a dozen privately owned commercial agroforests are in operation. We will attempt to synthesize the resulting 40 years of experience and to describe current agroforestry design principles for trees in pastures in this paper.

Hill Land Agroforest Development

Many southwestern Oregon hill lands were converted from oak woodland to improved grass/clover pasture during the 1950's through 1970's by clear cutting the hardwood trees and associated shrubs, then planting with a mixture of perennial grasses and subterranean clover. Although Douglas-fir is generally considered to be a relatively shade intolerant tree, it will successfully establish and grow under open canopy oak stands. In the Willamette Valley, survival and growth of Douglas-fir planted under thinned oak stands was equal to that where oaks were clearcut prior to planting (Jaindl and Sharrow 1988). The option of thinning rather than clear cutting oaks to establish an agroforest offers opportunities to increase both the biodiversity and the social acceptability of young agroforests. Oak woodlands are both aesthetically pleasing and provide important habitat for native plants and animals. The potential to jointly grow oaks, Douglas-fir, and pasture in hill land agroforestry systems may prove especially useful in designing productive, biodiverse, socially acceptable land use systems for the urban fringe.

Table 1 — Net cash flow per acre and internal rate of return (IRR) of 3 alternative land uses for western Oregon oak woodlands. Analysis is based upon a 20-year KMX hybrid pine rotation and 10% discount rate. Costs and incomes are best estimates based upon current market conditions and the experiences of local commercial agroforesters.

	Cash Income above Expenses					
Land Use	Year 1-5	Year 6-10	Year 11-15	Year 16- 20	Total	IRR
KMX Only	-$450	$128	$2205	$8000	$9673	19%
Sheep Only	$300	$300	$300	$300	$1200	29%
KMX+Sheep	-$51	$121	$135	$8144	$8349	22%

The price of timber has risen dramatically in western Oregon during the early 1990's, with trees that formerly sold for $200-300 per thousand Scribner board feet (MBF) now bringing $700-800/MBF. Landowners who would like to reap this potential windfall may be hampered by the long crop cycle of traditional forestry. The rotation length of a Douglas-fir forest is commonly 50-70 years in western Oregon. The initial cost of forest establishment (typically about $1200/ha) must be carried without any income until the first commercial thinning at approximately age 20 years. Since most of the income is generated when mature timber is harvested many years in the future, profits must be discounted for the decreasing buying power of money over time.

Producers may use fast growing trees such as KMX pine to speed up the crop cycle of forests and agroforests. The KMX hybrid pine is a cross between knobcone *(Pinus attenuata)* and monterey *(Pinus radiata)* pines. Local experience with KMX is that it grows over twice as fast as Douglas-fir or ponderosa pine on the same sites. This makes possible a 20-25 year timber rotation with KMX.

Agroforestry offers an approach to the cash flow problems of forestry by generating agricultural income during the early years following tree planting (Table 1). In effect, agroforestry offers landowners the steady annual cash flow of agriculture together with the high final payoff from

forestry investments. This is the most common reason for our producers to undertake agroforestry. It appears to be a better investment than either agriculture or forestry alone.

Agroforest Establishment

A pasture-based agroforest can be started from a brushfield, pasture, young forest plantation, or under a well thinned older forest. Whatever the origin, careful planning is needed to meet the needs of trees, forage, and livestock.

Moisture competition is generally the most critical factor limiting establishment of young conifers planted into pasture. Many studies (Cleary 1971, Cole and Newton 1986, Gourley 1990) have demonstrated increased survival and growth of conifers by keeping a weed free area within 1 meter of newly planted trees for the first three years after planting. Increased tree growth observed in silvopastoral agroforests compared to traditionally managed forests is often attributed to reduced competition between trees and other ground vegetation for soil moisture (Doescher, et al. 1989, Hedrick and Keniston, 1966, Sharrow 1994). Trees can be planted either before or after forage establishment. However, field trials (Fletcher et al. 1992, Logan 1986) have proven the practicality of establishing forage first, then spraying out a small area to plant young trees into. These weed free areas can then be maintained easily for the first few years and will provide adequate space for rapid growth of new trees. This scenario involves spring or fall pasture establishment, followed by tree planting the next winter. If trees are planted first, subsequent forage establishment requires the difficult operation of moving farming equipment around newly planted trees.

Large seedling stock types, particularly transplanted trees, are cost-effective in agroforests. While more difficult and expensive to plant, these trees have a higher tolerance to damage from livestock and will more quickly escape the maximum height of browsing by livestock and deer.

Choice of tree species to use is also an important concern. Trees vary greatly in their commercial value, rooting habit, adaptability to soil conditions such as seasonally high water tables, and growth rate and performance in the wide spacings common to agroforests. While it is possible and sometimes desirable to mix tree species in an agroforest, tolerance to shading requires careful consideration when deciding spacing and orientation of the trees. Douglas-fir and ponderosa pine are the most commonly used timber trees in western Oregon agroforests.

The number of trees to plant and planting pattern vary widely with the objectives of the agroforest. If the forest component is to be emphasized, stockings of 1000-1500 trees/ha are common, with grazing restricted to the first decade or so after tree planting. If grazing is to be maintained over a long time, lower tree stockings and frequent prunings will be needed to maintain forage production. Initial stockings of 500-1000 trees/ha are common in these settings, with subsequent thinnings reducing stocking to as few as 125 trees/ha at maturity. Tree density interacts with forest pattern. Pattern becomes increasingly important as density increases (Sharrow 1991). Conventional forests use rectangular grids of trees to minimize competition between trees at the expense of the ground vegetation. Square grids, single, double or triple rows, and cluster plantings have all been used in Oregon agroforests. The grid layouts optimize the area for tree growth, while the row or cluster plantings share the site resources more evenly with the forage crop. For example, a local agroforest model (Sharrow 1991) predicts that forage production of 10-year-old agroforests planted in grids will be only 1/3 as great as that of single tree rows planted at 500 trees/ha. The ease of access to row plantings for agricultural operations such as fencing, fertilizing, haying, etc. make them popular with producers. No rotation length tests of these various layouts are currently available.

Livestock Management

Potential browsing damage by livestock in young tree plantations is a critical concern for agroforesters. Commonly used conifer species in the Pacific Northwest can be subject to severe

browsing from wildlife in native forests. The intensive grazing regimes associated with improved hill pasture management present an additional browsing threat for trees planted into pastures.

Poor control of livestock or overgrazing can lead to removal of terminal leaders, substantial lateral branch defoliation and, more rarely, debarking (Black and Vladimiroff 1963, Logan 1980, Maki and Mann 1951, Sharrow 1994). Foresters have sometimes used this risk as a reason to discard the notion of establishing an agroforest. Total defoliation in unprotected environments can lead to plantation failure. Experience has shown, however, that wildlife and livestock browsing sustained in typical agroforestry operations does not constitute a significant risk to the survival of newly planted trees (Fletcher et al. 1992, Sharrow et al. 1992).

Young conifers are very tolerant of defoliation provided that the terminal leader is left intact. Osman and Sharrow (1993), for instance, reported that 75% lateral branch defoliation of 4-year-old Douglas-fir did not affect tree height and reduced current year's diameter growth by only 1.5% compared to undefoliated trees. Removal of terminal leaders is a more serious matter. Loss of conifer terminal leaders not only forgoes that year's height increment, it may also reduce diameter growth by as much as 30% (Sharrow et al. 1992). Risk of growth loss and tree deformation of young conifers in pastures is high enough to warrant either extra careful monitoring of forage availability and livestock grazing behavior during grazing periods or physical protection of the trees during the first few years after plantation establishment.

While livestock can safely graze new plantations, great care should be exercised when tree terminal leaders are within the reach of livestock. Pastures can be grazed during the spring growing period with negligible defoliation of trees provided that total utilization of forage does not exceed 35% of current season's forage crop (Fletcher et al. 1992, Sharrow et al. 1992). In fact, livestock damage to young western Oregon agroforests is often much less than that inflicted by native deer. The potential for tree damage by livestock appears to be related to several factors including season of year, percent utilization of forage available, age of animal, and height of tree (Sharrow 1994).

Conifers are chemically protected against herbivores. Their foliage is not particularly palatable to livestock at any time. Conifer foliage is most likely to be eaten in the spring when it is newly emerged and the anti-herbivory defense compounds have not yet fully accumulated, or any time that livestock consider themselves to be short of other food (Sharrow 1994). Livestock will consume conifer foliage in low amounts even when other preferred forage is available. This very low level of browsing often changes quickly into substantial levels of tree browsing as other forage is depleted. It is not unusual for over 90% of tree defoliation to occur in the last few hours of grazing when livestock are left too long in an agroforest. Livestock grazing young agroforests must be checked frequently and animals promptly removed when forage is depleted and they begin to actively feed upon trees.

In general, breed of livestock is not as useful a predictor of likelihood of damaging feeding behavior as is age, sex, and past experience of animals (Sharrow 1994). Older dry ewes do far less damage to trees than young lambs or rams. Agroforesters often avoid grazing very young plantations when ewes have new lambs at their side. Livestock which have regularly consumed either green foliage or dry needles in the past are much more likely to feed upon young trees in pastures. In every flock or herd there are individuals that seem to be predisposed to feed upon trees. Feeding behavior may be taught to others. Tree damagers should be culled as soon as they are identified. Some practitioners also report that livestock moved into agroforests from non-forested areas will browse young trees out of curiosity.

Fencing, tubing, repellents, and livestock exclusion have all been used to control browse damage by both wildlife and livestock in agroforests. Fencing works well when trees are concentrated in closely spaced rows to maximize grazing area and minimize fencing costs. Fencing can be permanent where continuous grazing is planned or wildlife damage to trees is a concern.

Portable electric fencing has been successfully used for short duration grazing. Lightweight portable fencing is quickly erected when and where needed to protect trees from livestock, then moved as livestock move to new areas. Fences provide a barrier between the trees and livestock, so monitoring of the grazing progress is not as critical as with open grazing.

Protecting individual trees with plastic mesh or rigid tubes has also been used successfully in agroforests (Fletcher et al. 1992, Logan 1980), but with complications. Tube removal by sheep and subsequent browsing of the unprotected tree is a real concern, so monitoring of the grazing is required. Attaching the tube firmly is another problem. Rigid wood stakes often break when rubbed by livestock. Resilient materials such as bamboo are more resistant to breakage.

Repellents have promise in preventing browse damage in agroforests but little actual testing has been done. A rotten egg repellant has been effective in protecting young conifers from sheep (Logan 1980), but observations suggest that this product may be somewhat phytotoxic to young conifers.

Another logical alternative for the agroforester is to simply remove the livestock from the plantation until the trees have reached a sufficient height or during seasons of the year when browse risk is high. On good sites in western Oregon and Washington, seedlings will reach two meters or more in height by the end of the fourth or fifth growing season. If browse damage from wildlife is not a concern, the agroforester may simply opt to leave the area ungrazed and the trees unprotected for the first 4-5 years.

Cost of tree protection systems vary considerably. Repellents are potentially the cheapest ($.10-.15 per tree); tubing ($.75-1.00 per tree) is the most expensive. Permanent electric fencing costs are variable depending upon type of fence installed and particularly the arrangement of the trees. Double or triple row agroforests greatly reduce fencing costs. While a single row system might cost $.60-.75 per tree, a double row could be protected for half this cost and a triple row system would cost in the $.20-.25 range per tree, which makes it more comparable to the repellant method. All methods have the advantage of controlling wildlife as well as livestock damage to young trees. Tubing, mesh caps, and repellents are often employed by local silviculturalists to reduce wildlife damage in commercial forests.

Pruning

Once trees are well established and have grown above the reach of livestock, management focus shifts to maintaining pasture production while maximizing the value of the logs being produced. Thinning and pruning of trees contribute to both of these goals.

Thinning will create space between tree crowns and allow sunlight to reach forage on the soil surface. For a typical hill land Douglas-fir agroforest in western Oregon, pruning will begin at 6-10 years of age, with 3-4 pruning lifts over a 10 year period and limbs removed to a final height of about 6m (Fletcher et al. 1992). Pruning will lift and narrow crowns of trees and allow light to better filter down to the soil surface. These practices will also counteract the negative wood quality characteristics associated with limbiness of trees at the wide spacings commonly used in agroforests. Open grown, low density plantation trees retain large limbs which form knots in the bole of the tree. Premium prices offered for knot free logs during the past 4 years has greatly increased interest in pruning as a means of increasing wood quality (ie. increase amount of knot free core) of logs in Pacific Northwest forests (Fight et al. 1993). Internal rates of return for pruning were recently estimated at over 9% for Douglas-fir and 7% for ponderosa pine (Fight et al. 1993). Widely spaced trees, such as in our agroforests, are especially responsive to pruning because of their tendency to produce and retain large lower branches and their rapid radial growth potential (Kellomaki et al. 1989).

Summary

Although the principles of silviculture and pasture forage production are well known, their combination into agroforestry systems is largely based upon hypothesis rather than field testing.

Clearly, we have much to learn about managed interactions between trees, animals, and ground vegetation in agroecosystems. However, agroforestry in western Oregon is now sufficiently developed that economically, biologically, and socially sound production systems have been designed and implemented by a core of early innovators. Awareness of agroforestry solutions to agricultural and silvicultural problems is slowly growing among local land owners. The relatively high profitability and social acceptability of well designed agroforestry systems ensure them a bright future in Western Oregon.

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Production Agroforestry Systems: Their Contributions to Sustainability in the Semiarid Western United States[1]

Peter F. Ffolliott and Kenneth N. Brooks[2]

Abstract — The production aspects of agroforestry systems that are suited for the semiarid southwestern United States are reviewed in this paper. Windbreaks, other planting arrangements, and silvopastoral systems are discussed in terms of their applications, design and management, benefits and limitations, and their role in sustainability. Although production benefits are emphasized, they cannot be separated from the environmental benefits gained from agroforestry systems.

Introduction

Agroforestry is a collective term that represents land use systems and practices in which trees and shrubs are combined deliberately with agricultural crops, livestock, or combinations thereof in spatial or temporal sequences (Raintree 1987). Production agroforestry emphasizes the production of one or more outputs to meet the basic needs of people, such as food, energy, raw materials, and cash.

Contributions of production agroforestry systems to the welfare of people in the semiarid western United States are reviewed in this paper. Windbreaks, other planting arrangements, and silvopastoralism are highlighted. Topics covered include—where these systems apply, how they function, alternative design conditions, benefits and limitations of the systems, and management needs to enhance their contributions to sustainability.

What They Are

Agroforestry systems are classified by Nair (1989, 1990, 1993) and others in relation to the spatial and temporal arrangements of their components, the importance and roles of these components, the productive outputs of the components, and the socioeconomic features of the systems. These general criteria correspond to the systems' structure (spatial arrangements, vertical stratifications, and temporal arrangements), function (production, protection, or combinations thereof), socioeconomic intents (level of managerial inputs, scale of management, and commercial goals), and ecological characteristics (environmental conditions and ecological suitabilities). These criteria also represent the broad categories for classification schemes of agroforestry systems.

This paper addresses the production functions of agroforestry systems. Importantly, the emphasis on the production of food, energy, raw materials, and cash outputs does not diminish the importance of environmental benefits and sustainability in any way. While production is stressed, it is the sustainability attribute that makes agroforestry different from other approaches to land and resource management.

Almost all agroforestry systems are multipurpose and, in general, have both production and protection functions (Nair 1989, 1990, 1993). The protection functions of agroforestry often contribute to the production functions by sustaining and, at times, increasing the production of outputs through the amelioration of microclimates and the protection of soil and water resources. Production agroforestry systems are distin-

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guished from conservation agroforestry by some people, who consider the latter to be where trees and shrubs are planted primarily for conservation and the environmental services they provide. The objectives of production agroforestry and conservation agroforestry are not necessarily mutually exclusive, however, with the goals of both systems usually being satisfied simultaneously.

Where They Apply

Where production agroforestry systems apply is determined largely by the type of agroforestry in question. Although countless production agroforestry systems and practices exist, we will focus on a few that are prominent in the semiarid western United States.

Windbreaks

Windbreak systems — where agricultural crops, livestock, or combinations thereof are protected from the damaging effects of prevailing winds and severe climates by border plantings of trees and shrubs — represent a main type of agroforestry in the region (Byington 1990) Windbreaks apply in situations where the production of agricultural crops or livestock is increased through their protection. The production of agricultural crops or forage can be increased by reducing evapotranspiration rates and improving soil moisture regimes on the leeward side of windbreaks. Livestock production can be increased when forage production increases leeward of windbreaks. In addition, livestock body weights increase when the animals are sheltered from hot winds and blowing dust in the summer and cold winds in the winter.

Windbreaks are common throughout the Great Plains region, where establishment and management of windbreaks began more than 100 years ago (Baer 1989). Nearly 225 million trees and shrubs were planted in windbreak configurations between 1935 and 1945, stretching 18,600 miles across 30,000 farms and ranches in mile-long, 8-to-10-row segments; these efforts continue today to varying degrees. Windbreak plantings are also found elsewhere throughout the semiarid western United States, from the Palouse prairies of Oregon and Washington, to the southwestern drylands of Arizona, New Mexico, and Texas.

Other Planting Arrangements

Trees and shrubs also are planted in a variety of other block and row arrangements in production agroforestry systems. Among the more commonly found block plantings in the region are fuelwood plantations, other woodlots that produce a variety of wood products, and Christmas tree plantations. Scattered trees and shrubs are planted (more-or-less) in blocks on pasturelands to increase their value for livestock production in a form of silvopastoralism (to be discussed below) and to make areas more suitable for wildlife.

Trees and shrubs are added to agricultural crops in row plantings to establish agroforestry cropping systems. Alley cropping is where trees or shrubs are planted in strips between agricultural crops, the latter providing short-term returns while the trees and shrubs are maturing. Such practices have been used successfully in the midwestern United States, where black walnut is intercropped with hay, wheat, and soybeans (Bandolin and Fisher 1991). On dry sites, however, alley cropping can reduce overall production if competition for soil moisture is too severe between crops and woody plants. Other forms of row plantings in which outputs are obtained include boundary plantings between ownerships and fields, live fences to keep livestock in check, and linear plantings in riparian ecosystems.

Planting of home gardens has a long tradition in the semiarid western United States. Home gardening consists of assemblages trees, shrubs, vines, and herbaceous crops adjacent to homesteads planted in blocks, rows, or random arrangements. Fruits, nuts, fodder, poles, fuelwood, and vegetable crops can be produced from home gardens. In addition to these products, trees in home gardens also provide shade for people and their animals. The varieties and extent of

home gardens in the region are largely unknown, although applications of this type of production agroforestry represent a significant land-use practice in aggregate.

Silvopastoralism

Silvopastoralism is another major type of agroforestry in the semiarid western United States region (Bandolin and Fisher 1991, Byington 1990). To some people, this land-use system, in which forests and woodlands are managed simultaneously for wood production and livestock, should not be considered agroforestry largely because of its large-scale implementation in the region. In its world-wide perspective, agroforestry is relatively small in its scale of implementation, being oriented to improve the livelihood of people on a local scale (Nair 1989, 1990, 1993). It is our opinion, however, that a discussion of production agroforestry systems in the semiarid western United States is incomplete without consideration of silvopastoralism.

Silvopastoralism is practiced on uncultivated rangelands that provide the "necessities" of life for grazing and browsing animals. The operative word here is uncultivated, as opposed to the periodic cultivation of smaller pasturelands. Unfortunately, the productivity of rangelands in the semiarid western United States is often constrained; these lands are fragile, easily damaged by abuse, and subject to droughts (Byington 1990, Herbel 1979, Holechek et al. 1989). Nevertheless, sustainability is possible on many sites with proper range management.

Rangelands in the region include the pinyon-juniper and encinal (oak) woodlands, and the western coniferous forests comprised mainly of ponderosa pine and Douglas-fir communities. The woody plant components on many of these rangelands renew themselves naturally, although trees are planted in some western coniferous forests to achieve the stocking conditions specified by management. Large-scale forest plantations in which free ranging livestock graze are not as common in the region as found in the southeastern United States (Pearson 1983, 1991); this agroforestry practice is gaining attention in the semiarid western United States (Avery and Gordon 1983), however.

How They Function

All agroforestry systems have specified functions (purposes) for which they specifically are suited. These functions are matched to people's needs and capacities of land to sustain the agroforestry systems to the extent possible,

Windbreaks

Windbreaks function to maintain and, in many instances, increase the flows of food, energy, and other outputs. Windbreaks also have the potential to reduce the demands for non-renewable resources at the same time (Bagley 1988).

Three "zones of influence" are delineated when discussing how a windbreak functions to increase production - a windward zone from which the wind blows, a leeward zone on the side where the wind passes, and a protected zone in which wind velocities are reduced. In the protected zone, evapotranspiration rates are often reduced which improves soil moisture conditions for agricultural crops or forage plants. This leeward zone is where production of agricultural crops would be expected to increase. Increases in production range from 5 to 25 percent (Bates 1944, Brandle et al. 1984, Frank and Willis 1978, depending largely upon the nature of the crop, climate, soils, and design of the windbreak planting.

In addition to increased forage production leeward of windbreaks, the protection of livestock from wind can also improve animal performance. Weight gains of livestock (cattle) can be increased by 25 percent on the leeward side of porous barriers, largely because stresses on the animals are lowered and, as a consequence, more energy is converted into body weight (Baer 1989, Moysey and McPherson 1966).

Other Planting Arrangements

Other planting arrangements in agroforestry systems function to increase the overall production of wood, agricultural crops, and sometimes livestock. When trees and shrubs are intercropped with agricultural crops, each crop utilizes a different ecological strata; each crop usually has different growth requirements and phenology. Planting of trees and shrubs on sites not suitable or accessible for agricultural crops provides a means to effectively use all of the farmland to produce a crop of some kind.

Incorporating woody perennials into other cropping or grazing schemes also provides some degree of resiliency for sustaining some productivity during periods of drought. For example, certain multiple purpose trees can provide nuts, fuelwood, and forage for livestock during periods when the production of crops and grasses is minimal.

Silvopastoralism

Silvopastoralism functions in the semiarid western United States to provide a diversity of wood products and sustainable production of cattle, sheep, horses, or goats. The mostly-publicly owned rangelands on which silvopastoralism is practiced are managed largely in reference to the ecosystem approach, which broadens the "resource-oriented" multiple-use paradigm to one of holistically-conceived ecosystem management. Other functions of these rangelands relate to wildlife resources, watershed protection, and recreation and tourism.

However, the simultaneous production of wood for fiber and forage for livestock often is the primary function of silvopastoralism on these rangelands. Managers, therefore, need to appreciate the relationships between forest and woodland overstories and the associated herbaceous understories to properly manage rangelands to maximize the joint production of these outputs. A number of such relationships have been established for this purpose (Ffolliott and Clary 1982), almost all of which show a competitive relationship between wood and forage, that is, one output increases while the other decreases. Optimal combinations of wood and forage must be determined in these instances.

Production economics provide a framework in which the optimal combinations of wood and forage can be determined. Clary et al. (1975) used this framework, in which production functions and relationships between resource values are analyzed in relation to specified managerial criteria, to estimate the optimal outputs of wood and livestock on a ponderosa pine-bunchgrass rangeland in northern Arizona. Their results indicated that this optimal level is attained, on a 1-acre basis, at an annual production of 100 board feet of wood and the level of forage production that supports a livestock carrying capacity of 10.5 yearling-days. While only illustrative, this study shows how optimal combinations of wood and forage can be determined for efficient silvopastoralism practices.

Alternative Design Considerations

Given the large diversity of products and options available, it is not surprising that there are alternative designs for the implementation of production agroforestry systems. This is true for windbreaks, other planting arrangements, and silvopastoralism in the semiarid western United States.

Windbreaks

Windbreak plantings have many orientations and patterns. Parallel plantings that are perpendicular to the prevailing wind are generally prescribed when winds prevail from one direction. A "checkerboard" pattern can be selected as an alternative planting pattern when the winds originate from different directions. Windbreaks around buildings are often planted in L-shaped patterns across the prevailing winds.

There are alternatives to the planned height of the windbreaks and their density. The area protected by a windbreak planting is proportional to

the height of the barrier (Finch 1988). Therefore, the taller the trees in the windbreak, the larger the protected area will be. The effectiveness of windbreaks is influenced greatly by their density. Optimal densities are 50 to 60 percent (Hagen 1991, Hagen and Skidmore 1971), so management practices should be directed toward this condition.

Spacings of trees and shrubs within windbreaks dependent upon the species planted, desired density of the barriers, and number of rows in the windbreaks. Windbreak plantings of different species of trees and shrubs can be prescribed to attain maximum effectiveness. Low trees or shrubs are planted on the outside windward side, followed by medium-size trees, and taller trees whose crowns break up the upper wind flows into eddies; a similar pattern is planted on the leeward size when spacing permits. The width of windbreaks depends largely upon the amount of land to be devoted to the plantings, and the number of rows required to maintain the desired density. Windbreaks up to 5 rows are effective and, in most instances, not too difficult to maintain. At the other end of the spectrum, 1-row windbreaks are risky, since holes develop and funnel winds onto the lands being protected.

Trees and shrubs that are selected for windbreaks plantings should be resistant to the force of winds, achieve rapid height growth, possess deep root systems, and have value for wood products. It is rare that one species will have all of these characteristics, in which case combinations of tree and shrub species are needed in windbreak plantings, as suggested above.

Other Planting Arrangements

A variety of alternative designs for block and row plantings of trees and shrubs are available. Block plantings are found in plantations and woodlands of varying sizes, spacings, and compositions. Sizes of blocks are dictated largely by the amount of land that is made available by its owner for wood production vis-a-vis agricultural crop production. The spacings of trees and shrubs in the blocks are selected to accommodate silvical requirements and achieve silvicultural prescriptions. Also, the potential risk of losses that are more frequent with monocultural plantings can be reduced by planting more than one tree or shrub species. Species composition should relate to both economic and environmental goals.

Other considerations in dryland environments include planting in concert with water harvesting techniques to improve productivity (Fowler and Ffolliott 1989). By incorporating water harvesting into agroforestry systems, a greater variety of plant species can be considered than would otherwise be possible because of inadequate rainfall. Otherwise, only drought tolerant species can be considered in most instances.

The seasonal patterns of rainfall should be considered in developing agroforestry systems. In the southwestern United States, for example, double-cropping can be possible because of the bimodal distribution of rainfall (Bandolin and Fisher 1991). The potential for increased productivity is apparent in such instances.

Most of the points made above also apply to row plantings. In many respects, row plantings represent linear plantations, including windbreak systems.

Silvopastoralism

Spacing patterns of trees and shrubs specified by silvicultural prescriptions influence the amount of forage available to livestock. The silvicultural treatments prescribed depend largely upon the woodland or forest type of the rangelands, whether even-aged or uneven-aged silviculture is to be practiced, and the goals of multiple use (Everett 1987, Ffolliott et al. 1992, Schmidt 1988, Tecle et al. 1989). The greatest amount of forage is found on rangelands where silvicultural treatments result in the greatest reduction in overstory densities. However, cutting restrictions in recent years has substantially restricted the amount of wood that is harvested in the region, limiting the silvicultural alternatives available to managers in the past.

Alternative systems of grazing livestock are also available. Selecting a grazing system is based

largely upon the climate, terrain, vegetation, kind of livestock, labor requirements, and extent of fencing, stock tanks, etc. Much of the livestock grazing in the pinyon-juniper and oak woodlands is either "transitional" between the summer and winter seasons or continuous throughout the year. Livestock grazing in western coniferous forests occurs in the late spring-to-early fall period (Holechek et al. 1989, Vallentine 1990).

Grazing with more than one kind of animal, referred to as common use, has the potential to improve overall productivity of silvopastoral systems. A more efficient utilization of both woody and herbaceous plants can be gained by such means.

Management Needs

A question occasionally asked in discussions about land-use systems in the United States is whether agroforestry options are necessary? Another question asked is how are low-input agroforestry practices relevant to the commercialized, specialized, and modernized agricultural production and forestry enterprises of this country and its largely urbanized society (Nair 1993)? Fortunately, the roles of and opportunities for production agroforestry in the United States have been reviewed by Gold and Hanover (1987), Lassoie et al. (1991), and others. These reviews conclude that there are many possibilities and opportunities for agroforestry, although developments in production agroforestry have been slow. Agroforestry developments in temperate-region countries are often constrained by a lack of land-use management institutions focusing on agroforestry, an adequate management-oriented research base, and a network of managers, researchers, and extension specialists committed to agroforestry development (Lundgren 1989, Thomas 1990).

Windbreaks

Management needs from a technical standpoint include the development of more suitable cultural treatments, better rehabilitative measures, and improved renewal practices. Trees and shrubs change their size and shapes as windbreaks mature, necessitating the prescription of cultural treatments to ensure the continuation of the sheltering effects. Prunings might be made to stimulate height growth, alter stem and foliage density, or remove damaged and dead branchwood. The removal of trees and shrubs by specified thinning schedules are required to keep the trees and shrubs at the desired spacings.

Better rehabilitative measures are necessary to sustain the structure of windbreaks that become ineffective in sheltering land. Proper schedules for the planting of new seedlings are required to fill gaps created when trees or shrubs die; importantly, these plantings become less effective as the windbreaks age and, as a consequence, size differences between the original and replanted trees and shrubs become greater. Pruning established trees and shrubs to stimulate coppice growth to retain foliage densities can also prove to be effective in rehabilitation, although the coppicing characteristics of the species must be known.

When and how to renew windbreaks once the trees and shrubs start to decline in growth and vigor or begin to die need to be determined. When to renew windbreaks depends largely upon the growth rates of trees and shrubs comprising the barriers, especially in terms of height, and the desired extent to the protected (leeward) areas; the latter is related directly to the height of the barriers. The time required for the tallest trees to reach the height at which the specified protected areas are attained represents the targeted renewal cycle. The height growth rates of the trees and shrubs must be estimated before efficient renewal schedules are adopted.

Options for renewing windbreaks must be found (Fewin and Helwig 1988). Such options include felling and replanting rows of trees and shrubs on the leeward side, planting new rows of trees or shrubs parallel to the older ones and then removing the latter, or planting trees or shrubs in rows between the existing barriers, which then are removed when the new windbreaks become effective.

Before agroforestry management practices can be assessed, differences in productivity between agroforestry and monocultural cropping systems must be determined. The Land Equivalent Ratio (LER) can be used to determine if greater yields are attained from agroforestry relative to optimally managed monocultures (Mead and Willey 1980, Vandermeer 1987). To determine the LER requires knowledge of crop outputs under agroforestry and in monoculture. Unfortunately, this information is incomplete or lacking for many of the tree, shrub, and herbaceous plant combinations commonly found in production agroforestry systems throughout the semiarid western United States.

Other Planting Arrangements

Suitable cultural treatments, better rehabilitative measures, and improved renewal practices are needed for block and row plantings in general. Therefore, some of the same technical considerations made above apply here, although windbreak density may not necessarily be a factor in management.

Also needed are methods to ascertain the level of economic returns from the different planting arrangements. Crop outputs must be evaluated at comparable places if the economic flows of benefits are to be meaningful.

Silvopastoralism

Silvopastoralism practices on publicly owned rangelands managed for multiple use are adaptable to such local conditions as the woodland or forest ecotype, the owner's goals and objectives, markets, land-use policies, and available technical and funding assistance (Byington 1990). Nevertheless, each of these practices should reflect the basics of wood and livestock management, and be able to "compete" with outputs from monocultural practices.

A research base has been generated to provide inputs to the management for wood and livestock in a multiple use framework on the woodland and forest rangelands in the semiarid western United States (Aldon and Shaw 1993, Baumgartner and Lotan 1988, Everett 1987, Ffolliott et al. 1992, Kaufmann et al. 1992, Schmidt 1988, Tecle et al. 1989). This management-oriented research continues, benefitting the practitioners and extension specialists involved in silvopastoralism in the region. A challenge confronting researchers is obtaining the information necessary to sustain silvopastoralism in the face of the cutting restrictions and other environmental constraints of recent years. These restrictions substantially limit the amount of wood that is harvested from public rangelands and the number of livestock that can graze these lands.

It is necessary, therefore, that viable options that recognize the complex relationships between (and among) vegetation, herbivores, and ecosystem processes be developed for silvopastoralism to succeed. Appropriate silvicultural practices and livestock grazing systems must be found to accommodate the various demands on public lands if silvopastoralism is to remain sustainable.

Quantification of production functions and product-product (wood-livestock) relationships to optimize the economic returns from silvopastoralism is needed for the region. Such relationships have been developed by Clary et al. (1975) for the ponderosa pine forests of Arizona.

Geographical Variations

The types of production agroforestry systems that can be considered for an area depend largely upon climate, that is largely governed by temperature and precipitation regimes. The natural vegetation that occupies an area is largely the result of interactions of temperature and precipitation, which (in turn) are indicative of the production agroforestry systems suitable to geographical locations. Likewise, soil characteristics affect the geographic distribution of certain plants and, as a result, the types of agroforestry that can be practiced. It is beyond the scope of this paper to describe in any detail all of the geographical variations of production agroforestry systems in the

semiarid western United States. On a broad scale, however, certain generalizations can be made.

Windbreak plantings are found throughout the region, although the design criteria and species composition vary geographically largely in response to annual precipitation regimes. Multiple-row windbreaks of more than on species comprise many of the windbreak systems in the higher-altitudes and higher-latitudes where precipitation is up to 40 inches annually. One or two rows of one species often comprise the windbreak plantings where precipitation regimes are more limiting, approaching 12 inches annually. Exceptions are found throughout the region, however.

A variety of agroforestry practices is found in rainfed areas receiving 25 inches or more of annual rainfall. Irrigation increases the area on which specific combinations of plants are possible. Species composition within these combinations are controlled largely by the silvical demands of the trees and shrubs, the temperature and precipitation tolerances, and soil requirements of the plants. Varieties of species also add to the geographical variations of these intermixtures.

Livestock production in unconfined conditions is a frequent component of production agroforestry systems in which the sustainable production of agricultural crops becomes problematic. "True" silvopastoralism is practiced in the region on areas where annual precipitation is 10 to 15 inches. In contrast, large-scale livestock production usually requires greater amounts of annual precipitation.

Benefits and Limitations

Agroforestry systems are planned to optimize ecological conditions and economic concerns to obtain higher, more diversified, and more sustainable levels of production than can be accomplished with a single land-use system. It is necessary, however, to consider both the benefits and limitations of these interventions to assess the advantages of production agroforestry relative to monocultural land-use systems.

Benefits

Agroforestry systems often make more efficient use of resources than monocultures in that several vegetative layers utilize solar radiation inputs more efficiently, different depths of rooting systems increase the cycling of nutrients, and (in systems when livestock are included) unused primary production (forage plants) is used for secondary production (livestock). The hydrologic and nutrient properties of soils are also improved as a result of shading, reduction in rainfall compacting the soil surface, and mulching with implementation of these systems.

Timber, fuelwood, and a variety of other raw materials from trees and shrubs can be produced for subsistence purposes and sale. Efficiently implemented windbreak plantings, other planting arrangements, and silvopastoralism also result in increased yields and improvements in the qualities of agricultural crops and forage plants which have economic benefits. The incidence of total crop failures common to single-cropping or monocultural systems is lessened through the diversity offered by agroforestry. As a consequence of these benefits, the socioeconomic conditions of people are frequently improved through increases in employment and income, and reductions in the risks of production and monetary losses.

Most agroforestry practices are efficient land-use systems that combine modern technology and local experience, and are compatible with the culture of the people involved. In many parts of the semiarid western United States, there is a long history of these practices and variations of them, although they were not always referred to as agroforestry.

Limitations

The advantages must be weighed against the limitations or constraints in any assessment of resource management alternatives. Possible limitations include the competition between woody plants and agricultural crops for space, sunlight, soil moisture, and nutrients, which can reduce the

aggregate yields of crops. Introduction of adverse chemical substances from one plant component to another, a process known as allelopathy, can be another limitation to increasing the levels of production.

Regeneration of prolific tree and shrub species displaces agricultural crops on many sites. Trees and shrubs might also serve as hosts to insects and diseases that are harmful to agricultural crops. Furthermore, there is often a natural resistance by some people to displace agricultural crops with trees and shrubs, especially in situations where land is scare.

Agricultural, forestry, and livestock management practices can often require modification with the introduction of production agroforestry. Management, therefore, is more complicated and acquisition of additional managerial skills is necessary.

Values of Benefits

The benefits of production agroforestry systems must be distributed accordingly and equitably among the stakeholders involved. This task requires that the economic, environmental, and social values of the benefits are identified, quantified, and then allocated to appropriate stakeholders in an efficient manner.

Economic Values

A distinction between a financial and economic analysis should be made in considering the economic values of benefits from production agroforestry systems. A financial analysis takes the viewpoint of the private sector or individual, while an economic analysis assumes a perspective of the overall society. It is likely, therefore, that a financial profitability analysis is more appropriate than an economic analysis in valuing the benefits from windbreaks and other planting arrangements, as many of these plantings in the semiarid western United States are made on lands in the private sector. An economic analysis, in which subsidy expenses incurred by the public sector are also included, should be applied to value the benefits from silvopastoralism practiced on the publicly owned rangelands. In either case, economic values of benefits are largely site-specific and, as a consequence, only generalizations about the values are presented.

Benefits from production agroforestry systems in general are valued in terms of monetary amounts when products are traded in the marketplace. This valuing approach is most commonly used for wood products, agricultural crops, and livestock obtained through the implementation of these systems. Increases in the overall production capacity of these outputs are translated into additional sources of income.

Proxy values representing surrogate market prices are applied when the benefits themselves cannot be valued in the marketplace, and where available substitutes can be valued (Gregersen and Contreras 1979). For example, there is no market for the soil lost from wind erosion on agricultural fields in the Great Plains. However, one can place a value on this effect by comparing the market price of an eroded field with that of a nearby field protected by windbreaks. The difference in these values becomes a proxy value for the soil lost; this value is "realized" with the planting of windbreaks, reflecting an economic value for this intervention.

Environmental and Social Values

Environmental benefits of production agroforestry systems, such as reduced wind erosion and enhanced fish or wildlife habitat, are valued (when possible) by proxy values. Environmental benefits include reductions in surface runoff, nutrient loading, and sediments from reaching streams. Properly maintained covers of trees, shrubs, and herbaceous plants will likely improve the hydrologic response of an area and water quality. Increases in the content of soil nutrients through the addition and then decomposition of litterfall also occur.

Stabilization and improvement of the economies and general welfare of rural communities represent social benefits of production agro-

forestry systems that can be quantified through proxy values in some cases. Trees provide a pleasant visual environment in many dryland areas, in addition to providing habitats for song birds and other wildlife that improve overall livability. Developing proxy values for such benefits can be difficult, however.

Two final comments are made in relation to valuing the economic, environmental, and social benefits of production agroforestry systems. First, while the benefits from these systems are often considered only as increases in the levels of production, preventing declines in production through time are also benefits (Hoekstra 1990); this is a necessary function of any sustainable production system. Second, most of the benefits from agroforestry are delayed in time, while many of the costs must be incurred early. As a consequence, short-term forecasts frequently underestimate the benefits of agroforestry and can show it to be uneconomic.

Contributions to Sustainability

Sustainability is the essence of successful agroforestry practices. Sustainability entails long-term production of goods and services with a minimum of resource depletion and environmental deterioration (Brown et al. 1987, Conway 1985, Gregersen and Lundgren 1990). Such production of goods and services must be both viable economically and acceptable socially. To be sustainable, fiber, food, and raw materials are provided in the "near-term" for today's populations, while resources are retained for the use of future generations of people. Properly planned, appropriately implemented, and efficiently managed production agroforestry systems contribute significantly to all of these conditions.

Descriptions of sustainability mostly express the precept that people should not rob future generations to fulfill current needs. However, these descriptions are statements of an ethical position (Brown 1993), and do not necessarily provide much guidance as to how people might proceed toward sustainability. Reganold et al. (1990) describe sustainable farming systems as those which produce adequate amounts of food, protect resources in doing so, and are environmentally safe and profitable in their implementation. This description is both a definition of sustainability and a list of the conditions which must be met for sustainability to occur. It is our opinion that production agroforestry is also consistent with this definition and the conditions of sustainability.

Concluding Comments

Much of the information on production agroforestry systems and other forms of agroforestry in the semiarid western United States has been generated from a combination of applied research designed to solve specific problems, applying these research results in the field, and experiences gained from trial and error (Byington 1990). While this information helps to solve local problems, it has not been sufficient to provide a body of knowledge on the multidisciplinary orientations of agroforestry in many instances. However, this information is essential to designing and implementing efficient production agroforestry systems, and developing and teaching the appropriate land-use philosophy to manage these systems in a sustainable manner.

It is postulated here that agroforestry can be advanced by creating an area of specialization on production agroforestry systems. While some progress in this direction has been made in recent years, establishing such a specialization seems poised to continue at a rather lethargic level until there are major institutional changes (Nair 1993), and changes in people's perspectives of agroforestry. The opportunities and resiliency of agroforestry practices might stimulate these changes in a way that is similar to the interest in windbreak plantings following the Great Depression in the 1930s.

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Agroforestry and Wildlife: Opportunities and Alternatives[1]

Arthur W. Allen[2]

Abstract — Environmental quality and the presence of wildlife are often considered important elements in the quality of life by American agriculturalists. Consequently, for many producers the implications of farm management on wildlife play at least a minor role in land use decisions. Agroforestry is increasingly recognized as a viable use of agricultural land that has the potential to provide both environmental and financial benefits. The conceivable size of agroforestry applications ranges from small acreages to large-scale, intensively managed, short-rotation biofuel crops. Integration of agroforestry practices into existing farming operations may enhance land productivity, contribute to greater sustainability of agricultural ecosystems, and enhance stability of producer income.

Introduction

American agriculture is governed by mechanized production dependent on agrochemicals, and is based largely on monocultural production (Buttel 1990; Soule et al. 1990; Cochrane 1993). Consolidation of farms, increases in field size, reductions in the variety of crops grown, and less frequent and varied crop rotations have contributed to a loss in the distribution, abundance and quality of idle, non-farmed areas across agricultural landscapes. These factors have been partially responsible for declines in wildlife populations (Warner and Etter 1985; Rodenhouse et al. 1993) as well as a diminished capacity for self-regulation inherent in natural plant communities associated with agriculture (Zanboni and Lorenzoni 1989; Altieri 1990). Although there are situations where endemic wildlife species may be negatively affected, agroforestry offers opportunities to restore habitat quality for other species by furnishing more complex patterns of vegetation in landscapes dominated by agriculture.

This paper concentrates on the potential landscape-level effects of agroforestry on wildlife associated with grassland and forest ecosystems. The wildlife habitat benefits of shelterbelts and windbreaks are well documented. Therefore, these practices are not addressed in detail in this report. Readers are encouraged to review Capel (1988), Johnson and Beck (1988), Cable (1991), and Schroeder et al. (1992) for overviews on shelterbelt design and associated wildlife benefits. Specific information on shelterbelt design can be obtained from the National Agroforester[3].

Relations Between Agroforestry and Wildlife Habitat

It is essential that the species of concern be determined before any particular effects of agroforestry on wildlife can be addressed. Wildlife associated with agricultural ecosystems may be broadly categorized as farmland or endemic species which often have conflicting habitat requirements (Allen 1993). For example, shelter-

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belts may negatively impact grassland-dependent species due to fragmentation of grassland habitat and ensuing elevated rates of predation and nest parasitism on grassland birds (Johnson and Temple 1990). Consequently, practices that are advantageous to one group of wildlife species may have detrimental effects on other species. Therefore, the influence agroforestry may have on habitat quality is defined as much by the spatial effects on cover type composition as it is by the type of forestry practice implemented.

Farmland Species

Some species of wildlife are adapted to the spatial and temporal patchiness associated with intensively managed agricultural landscapes. Wildlife species that thrive in agricultural ecosystems are typically habitat generalists [e.g., ring-necked pheasant (*Phasianus colchicus*), eastern cottontail rabbit (*Sylvilagus floridanus*), and white-tailed deer (*Odocoileus virginanus*)]. These species profit from the interspersion provided by shelterbelts and other woody vegetation in intensively farmed areas.

Endemic Species

In contrast to those species that have benefitted, other wildlife species have declined due to fragmentation and isolation of habitat resulting from agriculture and other land uses. Fragmentation occurs when habitats are converted into smaller patches which eventually become isolated within a background matrix of land use dissimilar from the original habitat. Disjunct, isolated remnants of habitat often impair the ability of species to successfully disperse and inhabit remaining sites that provide required habitat characteristics. Remnant patches of "natural" ecosystems surrounded by agricultural lands are vulnerable to both biotic and abiotic impacts from surrounding land uses (Whitcomb et al. 1981; Carroll 1990). Habitat isolation is a leading threat to many wildlife species in the North American temperate zone (Wilcove et al. 1986). The distribution of species associated with spatially extensive forest or grassland habitats have declined due to either deforestation or conversion of grasslands to agricultural production. Isolated and fragmented landscapes typically provide unsuitable habitat for large, wide ranging species; harbor disproportionately high numbers of predators; and are of insufficient extent to support area-sensitive species and those species susceptible to the detrimental effects of habitat edge.

Habitat isolation is a function of both the distance of the relict tract from other similar habitats and the characteristics of the landscape in which the remaining habitat is embedded (Matthiae and Stearns 1981; Knaapen et al. 1992). Boundaries between dissimilar land uses vary in their permeability with respect to wildlife movement (Wiens et al. 1985). The degree of permeability between cover types is a continuum that is species-specific and is defined by the biology of the species and the physical characteristics of the cover types. Some habitat types are more inhospitable and difficult to penetrate for some species of wildlife than for others. The more dissimilar adjacent habitat types are the more likely that movement will be impeded and habitat use will be reduced for species with specific habitat requirements. For example, row crop fields adjacent to existing woodlands will provide a barrier of unsuitable habitat for avian species dependent on forest ecosystems. A tree plantation adjoining existing woodland, however, may provide the structure needed for some use of the plantation by forest-dependent species and a corridor for movement to other suitable habitats even though the species and physical structure of plantation trees are dissimilar to the original woodland.

Grassland Species

Avifauna endemic to grassland ecosystems [e.g., grasshopper sparrow (*Ammodramus savannarum*), Baird's sparrow (*A. bairdii*), and mountain plover (*Charadrius montanus*) have experienced more severe and geographically widespread declines than any other guild of North American

wildlife, including forest-dependent neotropical migrant birds (Knopf 1993). The continued loss and fragmentation of grassland ecosystems have contributed to these declines, as has deliberate and unintentional introduction of woody vegetation in ecosystems historically dominated by grassland (Johnson and Temple 1990; Knopf 1992; Robinson et al. 1993). Extensive riparian forests along Great Plains rivers established by hydrologic changes and fire suppression in grassland ecosystems have encouraged westward emigration of wildlife species more characteristic of eastern forests (Knopf 1986, 1992). These species have displaced some grassland species and have contributed to elevated rates of predation and nest parasitism on species endemic to grassland habitats. Agroforestry may result in further habitat losses for these species if forestry practices are inserted into remaining extensive tracts of grassland. There are, however, options that can ameliorate some of the negative impacts of agroforestry on species endemic to grasslands.

Mitigating Negative Effects of Agroforestry on Grassland Wildlife

Diminished availability and quality of grassland nesting cover, higher predator-prey ratios, and the tendency for predators to hunt along vegetation edges contribute to lower nest success of both game and non-game birds in agricultural landscapes (Snyder 1985; Rodenhouse et al. 1993). Conservation of grassland avifauna is contingent, in part, on reducing practices that increase encroachment of woody vegetation into remaining contiguous tracts of grassland. Management practices that introduce woody vegetation into, or adjacent to, grasslands have the potential to further negatively impact grassland species. To reduce these negative effects on grassland avifauna, preference should be given to locating woody plantings adjacent to existing farmsteads or to intersperse them with rowcrops, small grains, and existing woody vegetation rather than pastures, old fields, hay fields, or other uncultivated, non-woodland cover types. Placing agroforestry plantings within or adjacent to large tracts of existing grassland should be avoided. Plantings of trees and/or shrubs should be no closer than 45 m (150 ft) from the edge of remaining grassland tracts (Sample and Mossman 1990).

Forest Species

Agroforestry may offer opportunities to mitigate the effects of fragmentation and isolation of woodland habitat within agroecosystems. For example, in intensively farmed regions generally devoid of wooded cover, white-tailed deer are restricted to small remnant woodlots or flood-prone bottomland forests in winter (Nixon and Hansen 1992). These sites frequently provide insufficient shelter and have low survival rates for over-wintering deer. Agroforestry plantations situated adjacent to small woodlots could increase the effective area of these stands and improve their potential as habitat. Plantations could be situated to provide corridors for wildlife dispersal between existing forest stands or other key habitat elements such as wetlands. Although there is some apprehension about the potential biological effects of corridors (Simberloff and Cox 1987; Hobbs 1992), the planting of buffer strips along riparian zones and drainage canals, as well as strategic placement of windbreaks and shelterbelts, could reestablish linkages between isolated woodland habitats.

Recent investigations in California have documented agroforestry benefits to avian species within intensively farmed regions. Established to reduce the volume of potentially toxic runoff from agricultural land, eucalyptus (*Eucalyptus camaldulensis* and *Casuarina cunninghamiana*) plantations provided an element of habitat diversity in an otherwise intensively farmed landscape (Kelly et al. 1990). The trees furnished nesting habitat for resident species as well as shelter and foraging sites for migratory species. As might be expected, both the density and diversity of birds using these plantations increased as plantations matured.

As much as 100 million hectares (386,100 mi^2) of U.S. agricultural land may be suitable for biofuel production (Office of Technology Assessment

1993). A large percentage of this area will likely be devoted to production of trees as energy crops. Transportation costs will necessitate the concentration of biofuel crops in close proximity to power plants. Such large-scale agroforestry applications may offer opportunities to mitigate forest edge effects existing within smaller woodlots. The presence of large plantations adjacent to, or surrounding, remnant stands of woodland may result in a greater area of habitat that could benefit wildlife requiring forest-interior conditions [(e.g., Acadian flycatcher (*Empidonax virescens),* ovenbird (*Seiurus aurocappilus*, Kentucky warbler (*Oporornis formosus*)]. However, to attain possible benefits to forest species it will be necessary to devise harvest patterns similar to those described by Harris (1984) and Hunter (1990) for maintaining old-growth characteristics in forest ecosystems. Under such scenarios, the remnant woodlands would be focal points around which the biofuel plantations could be managed on a rotational basis to maintain portions of the plantation in all age classes.

Mitigating Negative Effects of Agroforestry on Wildlife

The spatial configuration of plantations established for biofuel or fiber production can be designed to enhance their value as wildlife habitat. Stands comprised of multiple species of trees rather than monocultures will provide greater structural and physical diversity within plantations. To further enhance vegetative diversity and habitat quality, the following should be considered: varying the spacing between individual trees and rows, shaping the rows or stands irregularly, planting in bands or strips, alternating bands of trees with herbaceous vegetation, and leaving areas maintained in herbaceous cover interspersed within or adjacent to plantations. Plantations adjacent to or near wetlands, draws, or other sharp breaks in topographic contour contribute to micro-site diversity possibly resulting in greater wildlife habitat value than stands more distant from such features.

Conclusion

Historically, agricultural and conservation objectives have been forged largely with divergent goals and limited reflection on relations between sustainable agriculture and environmental quality (Berner 1988; Reichelderfer 1990; Gerard 1994). Agricultural producers, as well as the agencies that support them, must incorporate an enriched understanding of long-term, large-scale implications of land use decisions if environmental goals (which should include a more stable source of income for agricultural producers) are to be realized (Pimentel et al. 1992; Barrett and Peles 1994). Long-term maintenance of desirable wildlife populations and effective preservation of environmental quality will succeed if goals are addressed on a multi-farm scale rather than within individual farms or on isolated wildlife management areas (Saunders 1994).

It is likely that agroforestry practices may be more attractive to the smaller agricultural producers than those controlling the bulk of commodity production. Many of these producers, whose numbers represent a large proportion of the current farm population, welcome land uses that offer alternative sources of income and enhance environmental quality. Opportunities to meet these social, environmental, and economic objectives will become more clearly defined as agroforestry gains acceptance. Although these practices may be new and potential for improving habitat quality in agricultural landscapes is, as yet, largely unproven, agricultural interests have allies in state and federal resource agencies. These personnel recognize the necessity to work cooperatively with farmers to integrate economically viable land use and wildlife management objectives.

With foresight and consideration of the effects of management practices on a spatial scale larger than the planting, agroforestry holds promise to provide both economic and environmental benefits from agricultural lands. Unfortunately, there presently exists little quantitative information on the effects of agroforestry on wildlife (Vergara 1986). However, the concepts presented in many of the publications referenced in this paper pro-

vide guidelines for habitat enhancement in agricultural ecosystems. The specific consequences of incorporating forestry into agriculturally dominated landscapes will vary based on the extent of the forestry practice and in response to specific wildlife management issues. Biologists from state fish and wildlife agencies can provide more specific, regional guidance on the alternatives needed to optimize integration of wildlife and agroforestry objectives.

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Agroforestry in Communities: A New/Old Approach[1]

Gerald F. Bratton[2]

Abstract — Today's urban forestry programs differ from the conceptual programs of the mid to late 1960's. The intent of early urban forestry innovators was to manage the entire urban forest ecosystem. Present day practice often addresses only a portion of the original concept. Most urban forestry efforts of today deal primarily with architectural uses (elements to define space, screen, etc.) and uses to meet the aesthetic needs of communities, while tend to neglect climate ameloration and engineering uses of trees. In 1991, the National Agroforestry Center, began a number of projects to adapt agroforestry technologies, common to rural agriculture, for use in communities to meet their natural resource conservation and environmental enhancement needs. Examples of technologies applicable for urban use include: buffer plantings such as riparian filter strips; energy conservation plantings such as windbreaks; and protection plantings such as living snow fences. When properly designed these technologies can improve water and air quality, conserve soil, manage drifting snow, conserve fuel and energy, and improve human environments. By applying agroforestry technologies, communities can make their urban forestry program more holistic and the urbanized ecosystem more sustainable.

Introduction

Forestry innovators of the mid to late 1960's and early 1970's era built the framework for the present day urban forestry program. Early urban forestry concept designers viewed the urban forest in much the same way a forest silviculturalist would view a native forest. The urban forest, and related resources, could and should be managed as a total ecosystem. Community trees are, by definition, a forest since they comprise "an ecosystem characterized by a more or less dense and extensive tree cover" (Society of American Foresters, 1971). Pre-1970's urban forests were virtually overlooked by city planners and managers and in many cases were severely abused and not recognized for the value they added to the community. It was clear to early urban forestry innovators that there was potential to begin a new concept for forestry in communities: manage both the aesthetic/intrinsic values of urban forests and the communities associated natural resources. In 1970, Ed Cliff, Chief of the Forest Service, said "We must recognize that America's forest wealth is not confined to rural areas. Trees in the city are being increasingly recognized as a vital asset in soil and water conservation and in upgrading the quality of an urban environment." (USDA Forest Service, 1970). Community trees not only serve as beautiful landscape plants but also protect air, soil, and water, conserve energy, and improve wildlife habitat. Properly designed tree planting projects that utilize agroforestry technologies can assist communities achieve the goal of a sustainable community ecosystem.

Over a period of years urban forestry has evolved away from the original concept. The devastation of urban forests by Dutch elm disease

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caused urban foresters to concentrate on single tree management and deviate from the community ecosystem concept. The lack of authority to manage trees on private property also lead urban forest managers away from total ecosystem management. Without the authority to control trees on private property in and around communities it was nearly impossible to manage the urban forest as an ecosystem. Most urban forestry efforts eventually concentrated on street and park trees within communities. Few programs dealt with sustaining the complete urban ecosystem and resulted in neglect of the community's basic natural resources (soil, air, and water). However, the need to manage the urban forest as a complete ecosystem continued to be stressed. For example, in 1983, Gary Moll of the American Forest Association, stated: "urban and suburban lands need to be managed as part of the environmental system, just like forest land, rangeland, wetland, and farmland" (Moll 1983).

Developing the Working Tree Concept

The "working tree" concept was originally developed and promoted by the National Agroforestry Center to assist agricultural managers understand why trees belong in their system. The agricultural community had difficulty recognizing how forestry was relevant to production agriculture. Keep in mind that many present day landowners or their ancestors had cleared the land of trees in order to farm. Many continue to resist incorporating trees into their farm program, thinking trees take up space from valuable crop land or rangeland. Simply replacing the term "forestry" with the term "working trees" made the concept more understandable. Working trees are planted in a specific place, in a specific design, for a specific purpose. These trees have jobs to do. They are tools, just like a tractor, disc, terrace, or waterway, to improve production and save resources.

Since the working tree concept seemed to help make the task of marketing agroforestry to farmers and ranchers somewhat easier, the Center decided to try the same approach to promoting the use of conservation trees in communities.

Working Trees for Communities

In 1991, staff at the Center developed the concept that tried-and-proven rural agroforestry technologies could be adapted for use in communities and adjacent interface areas to mitigate natural resource degradation and enhance environments. Some technologies could be applied within the confines of the communities while others should be strategically located in the sensitive rural/urban interface and within the watersheds that directly affect communities. A trial program was developed with the goal of providing communities with tools ("urbanized" agroforestry technologies) that would help sustain their ecosystem. The Center had already developed a promotional/educational agroforestry program for rural areas titled "Working Trees for Agriculture" (WTA) so it seemed appropriate to title the urban effort "Working Trees for Communities" (WTC).

The uses of trees in communities are extensive and variable. In *Urban Forestry* (Deneke and Grey 1978) the authors describe the benefits of the urban forest in five broad categories:

1. Climate Ameloration
2. Engineering Uses
3. Architectural Uses
4. Aesthetic Uses
5. Other Uses

Climate Ameloration

Urban forests for climate ameloration are managed in a manner that controls or affects solar radiation, air temperature, air movement, and humidity. Microclimates are created that may ameliorate climate sufficiently for human comfort. Windbreaks fit well in this benefit category.

Engineering Uses

Trees for environmental engineering uses are utilized in a highly specialized manner. Environmental engineering applications for trees include: snow control on roads, parking lots and

high use areas; soil erosion; water quality; wastewater management; traffic control; noise abatement; glare and reflection reduction; etc. Appropriate agroforestry technologies that could be adapted include: living snowfences, windbreaks, and similar "line" plantings.

Architectural Uses

Trees are used individually or collectively to: define space (i.e. enclose, contain, accent, enframe, link); screen, controlling a particular view; provide privacy by secluding a particular area; or entice, frame, or enhance a particular view. Agroforestry technologies can serve both architectural and conservation uses, for example, a one- or two-row tree planting could function as a windbreak and a screen simultaneously.

Aesthetic Uses

Trees are often used to enhance and enrich settings. Most any tree will accomplish this goal through it's own inherent beauty. They are naturally aesthetic elements in our surroundings. Agroforestry technologies provide some degree of aesthetic enhancement, but are not used solely for aesthetics. Agroforestry trees are "working trees" and are intended to perform a practical work function.

Wildlife Uses

Some urban forestry professionals list wildlife under aesthetic uses, but I contend that wildlife should be listed separately. In some cases, certain wildlife need to be discouraged from living in certain areas (birds near airports, parking lots, deer near community gardens, etc.). Working trees may be planted to increase wildlife populations and encourage or discourage individual wildlife species by choice of plant materials and design.

Other Uses

Some interest has been shown in converting agricultural acreages located in the urban/rural interface surrounding communities to "community forests." These plantations are often designed in a block forest or greenbelt with wildlife, outdoor education, or recreation as the primary use. The design often neglects the potential of the planting to be a source of income (lumber, fuelwood, fruit, nuts, posts and poles, and specialty or agricultural crops grown in association with the trees). The design could also include trees and shrubs to create future greenbelts; planted in wider pattern to allow for grazing by domestic livestock or in widely spaced rows with crops grown between (alley cropping); or designed to produce specialty crops resulting from or associated with trees and shrubs. By utilizing agroforestry technologies, properly designed rural/urban plantations could provide economic diversity and both short and long term financial returns to assist troubled community budgets and still meet the wildlife, educational and recreational needs of the community.

Agroforestry technologies are capable of enhancing each urban forest benefit discussed above. In many cases, a single agroforestry practice can meet several benefits at a time even though it was originally designed for a different purpose. For example, a buffer strip designed to reduce streambank erosion in a community park can, at the same time, filter contaminated surface water before it reaches the stream, increase wildlife habitat, screen out residences along the park boundary, soften the "ditch-like" appearance often associated with community streams, and provide a setting for a wooded walking/jogging trail.

The WTC Program Expands

In 1992, the Agroforestry Center initiated a Working Trees for Communities pilot project to: 1) test acceptance of the concept; 2) see if the con-

cept was relevant and applicable; and 3) test the economic feasibility of the concept. The Center solicited and cost-shared 12 demonstrations in six states. Examples of adapting agroforestry technologies to use in communities included: a wind protection/living snowfence to protect an entire community from high wind and snow; a windbreak around a grade school to cut heating fuel costs, make the playground more usable and provide for an outdoor laboratory; a greenbelt planted along a riparian zone to protect the fragile riparian zone and serve as a hiking and jogging area; a combination wind protection and visual/noise screen planting located near a recreation area and ball diamond; a living snowfence to protect highway entrances; etc. The project met with great success and the participating communities, state forestry organizations, and community residents overwhelmingly endorsed the concept.

After the successful pilot project, the Center and the National Arbor Day Foundation, sponsored a Working Trees for Communities Workshop. Key participants involved in the 1992 demonstration pilot were asked to analyze the project and decide if it was worthy of further effort. The consensus of the workshop participants was that the Working Trees for Communities project should be continued and they encouraged the Center to increase the scope and activities in 1993.

In 1993, it became apparent that no new funds would be available to continue the WTC project. The Center and partners were forced to search for an alternative source of funds. One choice was to locate funding outside normal governmental sources. The Center contracted with the Colorado State Forest Service (CSFS) to assess potential alternative funding sources for WTC projects. The CSFS then contracted with an environmental marketing consulting firm to organize a project at the new Denver International Airport. The firm also developed and incorporated a youth component to the project. In the spring of 1994, several hundred youth from Boys/Girls Clubs of America and Big Brothers/Big Sisters of America voluntarily planted 4 miles of living snowfences to protect a portion of the airport highway entrance from drifting snow. The children had a positive outdoor experience, the adult teachers and supervisors were pleased with the activity, and future motorists will be protected from unsafe driving conditions. Although there were few private funds involved the project was considered a success. The partners involved in this project agreed that WTC projects need to continue to utilize agroforestry technologies to mitigate community natural resource problems, involve youth, utilize private funds, and increase the scope to a national scale. As a result the Center proceeded to develop the next step in the process.

The Center and WTC partners agreed there was need to proceed to the next step in the process and continue the WTC project. It was recommended that a private nonprofit foundation be located to administer the project. The environmental marketing consultant involved in the Denver International Airport project was so enthusiastic about the potential of the concept that she agreed to create the Plant A Tree/Help A Kid (PAT/HAK) Foundation to continue the program. The intent of the newly formed foundation was to: 1) locate sources of outside funding (corporate, grants, etc.); 2) develop the youth participation component; and 3) solicit, promote, and follow WTC projects through to completion. The PAT/HAK Foundation has renamed the program, Working Trees for Tomorrow's Communities (WTTC) and is presently organizing a national program that will involve many youth groups, private organizations and businesses, and conservation agencies. A memorandum of understanding (MOU) between the USDA Forest Service and the Foundation has been developed wherein the Foundation will administer the project and the Forest Service will provide guidance and coordination assistance to the foundation. A second MOU between the USDA Forest Service, Natural Resource Conservation Service, Council of Western State Foresters, and the National Association of Conservation Districts has also been developed. This MOU delineates a WTTC advisory committee that will provide overall program guidance and direction to PAT/HAK. On-site field staff representatives of the participating agencies will be responsible for providing techni-

cal assistance on agroforestry technologies for WTTC projects located within their jurisdiction.

Summary

Since agroforestry technologies such as windbreaks, living snow fences, erosion control plantations, and riparian buffer strips provide conservation, economic, wildlife, and aesthetic value in rural America, it seems logical they would also have an important role to play in urban or community natural resource management. A 1992 and 1993 pilot program testing this hypothesis has shown it to be socially acceptable, viable, economically feasible, and national in scope. Current efforts are underway for the PAT/HAK Foundation to deliver a Working Trees for Tomorrow's Communities program nationally. The Foundation will be assisted by representatives of the National Association of State Foresters, the National Association of Conservation Districts and the USDA Forest Service, Natural Resource Conservation Service, and Extension Service. Individual projects will be: designed by local natural resource professionals employed by the agencies mentioned above; funded by private sources; and implemented by youth groups/organizations. Working trees in the form of windbreaks, snow fences, streamside buffer strips, and other agroforestry technologies may soon become common place in communities across the nation. They will, like their rural counterparts, conserve our natural resources and make life safer and more pleasant for community dwellers.

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Windbreaks and Specialty Crops for Greater Profits[1]

James R. Brandle, Laurie Hodges, and Joel Stuthman[2]

Abstract — Trees and shrubs have an important role to play in today's integrated agricultural systems. Planted as windbreaks, they provide wind erosion control, improve crop yields, and enhance the quality of many wind-sensitive crops. When properly designed, windbreaks can also provide valuable products to enhance the profitability of agricultural operations.

Appearance and quality are major factors in decisions by consumers to purchase specialty crops. Fruits and vegetables with blemishes caused by wind blown soil, abrasion, or sunburn are graded lower and receive lower prices. Many fruit and vegetable crops have shown significant yield increases as a result of shelter. In many cases, vegetables grown in shelter mature earlier, providing marketing advantages to producers in quality and price.

Incorporating fruit or nut trees and shrubs into a windbreak may offer opportunities for additional income. Fresh or dried fruits and nuts, jams, juices, and wine are some of the possible products. While high-quality fruit and nut crops require intensive management, less intensive operations can provide products suitable for local farmer markets or pick-your-own operations.

The integration of woody plants into the agricultural landscape provides habitat for many wildlife species. A diverse agroecosystem is more likely to resist outbreaks of certain insect and rodent pests due to the presence of natural predators. While some wildlife species may be incompatible with production of certain specialty crops for some markets, the presence of wildlife may provide additional income from fee hunting or other recreational activities, especially near urban centers.

The integration of agroforestry practices into sustainable agricultural systems focused on specialty crops requires careful consideration of all aspects of the operation, an understanding of basic ecological principles, and a working knowledge of local conditions and markets.

Introduction

The continental climate of the Great Plains is one factor limiting commercial vegetable production in the region. The climate-related combination of temperature extremes, temperature fluctuation, high winds, high evapo-transpiration, and low, erratic rainfall increases the risk to growers producing high-value, capital-intensive crops such as commercial fresh market fruits and vegetables.

The use of windbreaks to moderate climatic extremes dates back to the 18th century when Scottish agricultural workers used hedges to protect their crops. Today, windbreaks are recognized not only for their influence on microclimate but also for their beneficial effects on crop yield and quality (Baldwin 1988; Brandle *et al.* 1988; Norton 1988). These benefits stem mainly from a reduction in wind speed and a modification of the microclimate in the sheltered zone.

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This paper addresses three aspects of windbreaks and specialty crops: 1) How does a windbreak work? 2) What are the benefits to specialty crops? and 3) How can agroforestry practices be incorporated into production systems to enhance total economic return?

Windbreak Mechanics

Microclimate

In general, wind flows across the land surface in a laminar fashion. As the air flows over the surface, a frictional drag develops slowing the wind near the surface. A rough surface tends to have greater frictional drag, slower wind speeds, and greater turbulence near the surface. A windbreak increases surface roughness and, when properly designed, provides areas of reduced wind speed useful for agriculture.

A windbreak is a barrier on the surface that obstructs wind flow and alters the flow patterns both windward and leeward of the barrier. As wind approaches the barrier the flow is forced up and the streamlines of air are compressed as they pass over the barrier (van Eimern *et al.* 1964). This upward movement begins at some distance from the windbreak and creates a region of reduced wind speed on the windward side of the barrier. The width of this region is proportional to the height of the barrier and extends out 2 to 5 times the height of the barrier. A similar but much larger region is created to the lee of the barrier and typically extends for a distance of 10 to 20 times the barrier height (Caborn 1957).

The size of these protected zones and the extent of the wind reductions within the zones are dependent on the structure of the windbreak (Heisler and DeWalle 1988). In particular, windbreak height and porosity determine windbreak effectiveness. In most cases a windbreak porosity of 40 to 60 percent provides the greatest degree of protection over the largest area. As porosity decreases, less wind passes through the barrier, wind speed reductions are larger, the area of protection decreases, and more turbulence is generated. In contrast, as porosity increases, more wind passes through the barrier, wind speed reductions are smaller, the extent of the protected zone increases, and less turbulence is generated (Brandle 1990).

As a result of wind speed reduction and changes in turbulent transfer, the microclimate in the protected zones is altered. The magnitude of microclimate change for a given windbreak depends on the existing atmospheric conditions; on the windbreak's height, porosity, and orientation; and on the time of day. In general, air temperatures tend to be several degrees warmer in shelter; however, on very calm nights temperatures may be 1 to 2 degrees cooler (Argete and Wilson 1989). Soil temperatures tend to be slightly warmer in shelter (McNaughton 1988), especially early in the season. Rainfall over most of the sheltered area is generally unaffected except in the area immediately leeward of the barrier (van Eimern 1964). In contrast, snow accumulations leeward of dense windbreaks will add significant moisture to the area adjacent to the barrier. If the windbreak is more porous, snow distribution in sheltered areas is more uniform and may be a significant factor determining crop productivity (Scholten 1988). Relative humidity is slightly greater near the windbreak (within 10H, where H is the height of the windbreak) and slightly lower beyond 10H due to an increase in turbulent transport (McNaughton 1988; 1989). Recent reviews by McNaughton (1988; 1989), Heisler and Dewalle (1988), and Argete and Wilson (1989) have discussed the relationships between windbreaks, wind speed, and microclimate in detail, and the reader is referred to these original works for a more complete discussion.

Plant Response

Wind influences plant growth and development in several major ways (Grace 1977; 1981; 1988) all of which may be modified by shelter. One useful concept in explaining plant response to shelter is that of coupling (Monteith 1981). Exchange processes between single leaves and the atmosphere, or between plant canopies and the

atmosphere, are controlled by the gradients of temperature, water vapor, and carbon dioxide that exist between the immediate micro-environment above the leaf or canopy and higher levels of the atmosphere. When these gradients are modified by shelter, plant process within the sheltered zone may become uncoupled and the driving forces for various exchange processes altered.

Near the windbreak, in the area of greatest protection, we expect conditions to be uncoupled as the canopy is isolated from the atmospheric conditions above the sheltered area. In contrast, as we move away from the windbreak, the degree of protection decreases, turbulence increases, and the plant canopy becomes more strongly coupled to the upper levels of the atmosphere. In either case we can expect to see the exchange rates for heat, water vapor, and carbon dioxide altered (Grace 1988; McNaughton 1983; 1988; 1989).

Temperature in shelter generally increases, particularly within 8H of the windbreak. This can be an advantage since small increases in air temperatures may have substantial positive effects on the rate of growth and development of the crop.

The influence of windbreaks on plant water relations is complex. Transpiration rates may either decrease or remain the same depending on atmospheric resistance and saturation vapor pressure deficit (Grace 1988). Evaporation rates are reduced in shelter (McNaughton 1983), water use efficiency is enhanced (Davis and Norman 1988; Grace 1988), and as a whole, plant water stress is reduced (Grace 1988). However, sheltered plants tend to be larger and have greater leaf areas, and under conditions of limited soil moisture, may actually suffer greater water stress than exposed plants (Grace 1988).

Wind also influences plant growth directly by the mechanical manipulation of plant parts. This movement may increase radial enlargement, reduce stem elongation (Jaffe 1976), or affect cellular composition (Armbrust 1982). The effect may be manifested by changes in plant hormone levels or may result from direct damage to the plant tissue. Indirectly, wind-blown soil contributes to leaf, stem, flower, or fruit abrasion and may result in increased water loss due to cuticular damage (Grace 1981), decreased fertilization, and loss of quality in the crop.

Specialty Crop Response to Shelter

The effects of wind protection on the production of vegetable, orchard and other specialty crops were reviewed most recently by Baldwin (1988) and Norton (1988) as part of the First International Symposium on Windbreak Technology (Brandle *et al.* 1988). Earlier reviews by van Eimern *et al.* (1964), Waister (1972), Grace (1977) and Sturrock (1984) provide a historical look at the influence of wind on vegetable production. Using these earlier reports as background, we will review current literature and include data from our ongoing studies at the University of Nebraska.

Wind Erosion and Soil Abrasion

Wind erosion and abrasion of young seedlings is a major cause of damage to specialty crops in semiarid areas (Baldwin 1988). Efforts to control wind erosion are usually designed to reduce erosion below the tolerance level of the soil but rarely take into account the tolerance of the crop to damage by wind blown soil (Finch 1988). Many of the vegetable and other specialty crops have extremely low tolerances, making protection of the crop critical to successful production in the region.

Mechanically-Induced Stress

Mechanically induced stress occurs when the above ground portions of the plant are disturbed. Wind is the primary casual agent, and exposures as low as several minutes per day of mild wind (<4 m sec^{-1}) may cause damage in some species. The response can take many forms; the most noticeable are reduced growth of aerial portions of the plant and thickening of the stem. Other

manifestations of wind damage include: epinasty, increased chlorophyll concentrations, reduced or delayed flower production, increased susceptibility to fungal disease, enhanced bud dormancy and lower phototrophic and gravitropic responses (Biddington 1986).

Extreme wind events can cause extensive damage to a number of crops. While windbreaks provide little protection against events such as tornadoes, they do provide protection from winds up to 20 to 25 meters per second (50 to 60 mph). For example, on July 8, 1993, a storm with average wind speeds of 40 m sec^{-1} was recorded at the shelterbelt research area of the University of Nebraska-Lincoln, Agricultural Research and Development Center (ARDC) near Mead, Nebraska. Cantaloupe vines in the exposed areas were blown to one side of the raised beds and some plants were partially pulled from the soil by the wind action (fig. 1). In areas sheltered by windbreaks, no such damage was recorded.

Figure 1 — Wind damage to cantaloupe plants in unsheltered areas exposed to winds of 40 m sec^{-1} on July 8, 1993 at ARDC, Mead, NE. Note that the roots have been pulled from the soil.

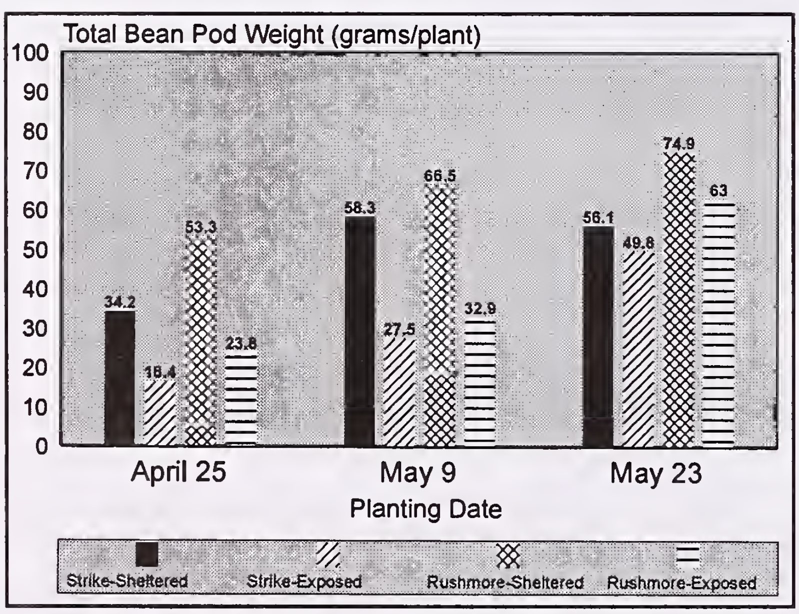

Figure 2 — Preliminary data on yield of sheltered and exposed snap beans from three planting dates at ARDC, Mead, NE. Total bean pod weight per plant is the mean of 51 plants from four replications with two samples per replication. No statistical analysis has been done on the data at this time.

Crop Yield and Quality

Windbreaks increase yields of vegetable and other specialty crops in the order of 5 to 50 percent. Van Eimern *et al.* (1964), Waister (1972), Sturrock (1984), Baldwin (1988), and Norton (1988) provide comprehensive reviews of literature published prior to 1988; however, little information is available from locations in the western United States. In Nebraska, studies on sugar beet indicated increases of 8 percent with shelter, with greater increases in dry years (Brown and Rosenberg 1972). Bagley and Gowen (1960) reported increased yields of up to 60 percent for tomatoes and up to 37 percent for snap beans. Both studies were done behind slat fence barriers with porosities of 50 percent.

On-going studies at the University of Nebraska, Agricultural Research and Development Center (ARDC) on snap bean (Suratman, unpublished data), cabbage and cantaloupe (Zhang and Daningish, unpublished data) indicate increases in early yields. In the case of both spring and fall planted cabbage, average head weight of plants grown in shelter was increased 14 to 18 percent and maturity advanced by 5 to 10 days (Hodges and Brandle 1994).

Preliminary data on early yields of two snap bean varieties from three planting dates indicated a definite advantage for the sheltered crop especially for the first two planting dates (fig. 2). These yield increases and the earliness of the yields have a significant impact on the economic benefits of snap bean production. Using Chicago wholesale prices, sheltered plots had increases in value of over 100 percent for the first two planting dates and 13 to 19 percent for the later planti-

ng date (table 1). The increases are most likely due to more rapid rates of plant development as a result of increases in temperature in the sheltered areas (data not presented).

In a three-year study of the effects of shelter on cantaloupe production at ARDC, early yields were increased in 1991 and 1993 but not in 1992. For example, both the early marketable yield and the total yield were greater in shelter for the first five harvest dates in 1993 (fig. 3). Using Chicago whole-

Table 1 — Preliminary data on economic return of snap beans from three planting dates in sheltered (SH) and exposed (EX) conditions.

	Planting Date = April 25 Harvest Date = July 4 Price[1] = $14.00/30 lb crate			
Cultivar	**Strike**		**Rushmore**	
Treatment	**sh**	**ex**	**sh**	**ex**
lbs/acre[2]	5,227	2,509	8,154	3,624
# of 30 lb crates/acre	174	84	272	121
$/acre	2,436	1,176	3,808	1,694
	Planting Date = May 9 Harvest Date = July 8 Price[3] = $22.00/30 lb crate			
Cultivar	**Strike**		**Rushmore**	
Treatment	**sh**	**ex**	**sh**	**ex**
lbs/acre	8,921	4,182	10,106	5,018
# of 30 lb crates/acre	297	139	337	167
$/acre	6,534	3,058	7,414	3,674
	Planting Date = May 23 Harvest Date = July 23 Price[3] = $17.00/30 lb crate			
Cultivar	**Strike**		**Rushmore**	
Treatment	**sh**	**ex**	**sh**	**ex**
lbs/acre	8,573	7,597	11,430	9,618
# of 30 lb crates/acre	286	253	381	321
$/acre	4,862	4,301	6,477	5,457

[1]Prices are based on the Chicago wholesale market.
[2]Based on 69,696 plants per acre.
[3]Price reflects unusual weather conditions in major snap bean growing areas.

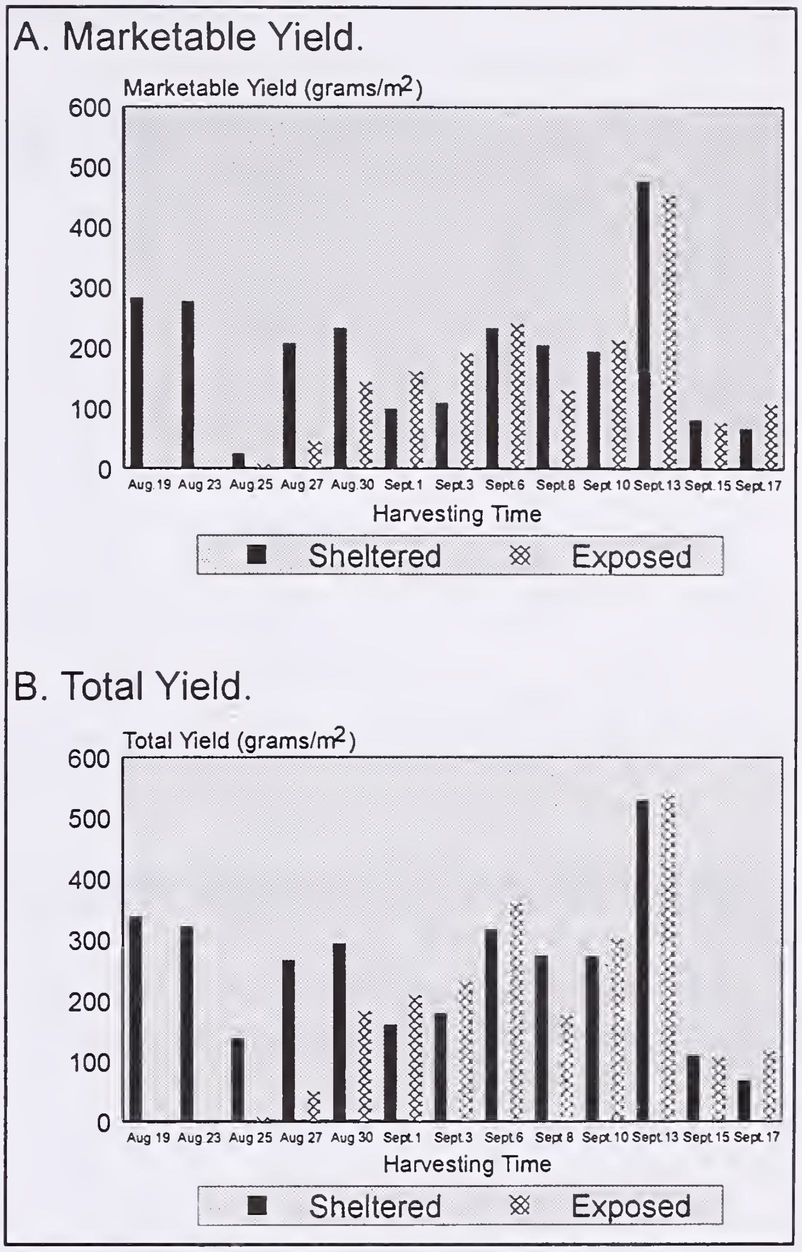

Figure 3 — Marketable and total yield of cantaloupe from sheltered and exposed plots over the 1993 growing season at ARDC, Mead, NE.

sale prices, this translates into a 38 percent increase in value for the 1993 growing season (table 2).

It is somewhat disappointing that additional studies of the effects of shelter on high-value, wind-sensitive crops have not been conducted. These crops could provide significant income to producers in the region if cultural practices were developed to provide protection from wind and wind-blown soil. In this regard, the Department of Forestry, Fisheries, and Wildlife and the Department of Horticulture at the University of Nebraska have developed a cooperative research program to document the impacts of shelter on commercial vegetable production in Nebraska.

Table 2 — Comparison of cantaloupe yield and value from sheltered and exposed plots during 1993 at ARDC, Mead, NE.

Date	Price[1]($)	Sheltered Lbs/acre	Sheltered # 40 lb cartons	Sheltered $/acre	Exposed Lbs/acre	Exposed #40 lb cartons	Exposed $/ACRE
Aug 19	8.50	2,528	63	535	0	0	0
Aug 23	8.50	2,472	62	527	0	0	0
Aug 25	8.50	221	5	42	61	1	8
Aug 27	8.50	1,853	4	391	396	10	85
Aug 30	8.50	2,077	52	442	1,283	32	272
Sep 1	8.50	889	22	187	1,437	36	306
Sep 3	9.50	970	24	228	1,714	43	408
Sep 6	9.50	2,074	52	494	2,146	54	513
Sep 8	9.50	1,833	46	437	1,158	29	275
Sep 10	9.00	1,735	43	387	1,902	47	423
Sep 13	9.00	4,255	106	954	4,057	101	909
Sep 15	9.00	730	18	162	691	17	153
Sep 17	9.00	598	15	135	959	24	216
Totals		22,235	554	4,921	15,804	394	3,568

[1]*Based on weekly reports from the Chicago wholesale market, 12 melons/40 lb carton.*

Agroforestry and Specialty Crops

Agroforestry has been defined as: *an intensive land-management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock.* (Garrett *et al.* 1994)

The definition is such that a wide variety of practices including: riparian vegetative buffer strips, alleycropping systems, silvopastoral systems, windbreak systems, and natural forest/specialty crop systems can be classified as agroforestry practices. In this paper we have limited our discussion to those practices where a windbreak system is modified to produce a product for sale. These products can take many forms. We have divided them into three categories: 1) **crops from windbreaks** - the windbreak produces fruits or nuts which can be sold directly or in some processed form; 2) **windbreaks as crops** - the windbreak is harvested to produce a product such as timber, Christmas trees, or nursery materials; and 3) **protection benefits** - the windbreak produces a condition which has value, such as crop benefits or wildlife habitat. A summary of species adaptable to the Great Plains, and their potential uses are included in table 3.

Crops From Windbreaks

Incorporating fruit or nut trees and shrubs into a windbreak provides additional marketable products such as fresh or dried fruits and nuts, jams, juices, and wine. Brambles such as raspberries and blackberries may be planted in the outer rows of some types of windbreaks, providing fruit for sale at farmers markets, pick-your-own operations or home use. If they are planted as barriers between other crops, they provide supplemental wind protection within the field as well as a marketable fruit.

High-quality fruit and nut crops require intensive management and generally include irrigation systems and high levels of pest control. However, the growing demand for organically produced fruits and vegetables is beginning to add to market value and may provide a local niche for a specialized product. Increasing the degree of on-farm processing also adds value to the product and may provide a greater economic return.

A windbreak is an ideal place to keep bee colonies. Bees are more active in sheltered areas and their hives can be moved to facilitate pollination of various specialty crops. Certain trees, such as black locust (*Robinia pseudoacacia*),

Table 3a — Conifers for use in agroforestry systems in the northern Great Plains[1].

Common name/species	Upland	Bottom Land	Protection Value[2]	Wood Products[3]	Christmas Tree/Nursery Materials	Wildlife Food & Habitat	Comments
Austrian Pine *(Pinus nigra)*	X		Good		X	X	Some disease problems
Balsam Fir *(Abies balsamea)*	X		Good	X	X		Very protected sites
Blk Hls Spruce *(Picea glauca densata)*	X		Excel.	X			
Blue Spruce *(Picea pungens)*	X		Excel.		X	X	
Concolor Fir *(Abies concolor)*	X		Excel.	X	X	X	Protected sites
E. Redcedar *(Juniperus virginiana)*	X	X	Excel.	X		X	Adapted to most sites
Jack Pine *(Pinus banksiana)*	X		Good	X			Very drought tolerant
Norway Spruce *(Picea abies)*	X	X	Excel.		X	X	
Ponderosa Pine *(Pinus ponderosa)*	X		Good	X		X	Drought tolerant
Rocky Mt. Juniper *(Juniperus scopulorum)*	X	X	Excel.			X	Drought tolerant
Scotch Pine *(Pinus sylvestris)*	X		Excel.	X	X	X	Sandy to loamy sites
White Spruce *(Picea glauca)*	X	X	Excel.	X		X	

[1]*Information sources: Dirr (1990), Henderson (1981), Burns & Honkala (1990a)*
[2]*Value as a windbreak species*
[3]*Wood products = timber, posts, poles, chips & fuel wood*

Table 3b — Hardwoods for use in agroforestry systems in the northern Great Plains[1].

Common name/species	Upland	Bottom Land	Protection Value[2]	Wood Products[3]	Biomass[4]	Human Food Products[5]	Wildlife Food & Habitat	Comments
Am. Basswood *(Tilia americana)*		X	Good	X	X	X	X	Wood used for carving
Am. Sycamore *(Platanus occidentalis)*		X	Fair	X	X		X	Wet sites
Black Locust *(Robinia pseudoacacia)*	X	X	Good	X	X	X	X	Excellent fuel wood
Black Walnut *(Juglans nigra)*		X	Fair	X		X	X	Deep well-drained sites
Black Willow *(Salix nigra)*		X	Poor	X	X	X		Flood tolerant
Bur Oak *(Quercus macrocarpa)*	X	X	Good	X			X	Drought tolerant
Boxelder *(Acer negundo)*	X	X	Good		X	X		Tolerates poor soils
Cottonwood *(Populus spp.)*		X	Fair	X	X		X	Very competitive
Green Ash *(Fraxinus pennsylvanica)*	X	X	Excel.	X	X		X	Drought and flood tolerant
Hackberry *(Celtis occidentalis)*	X	X	Excel.	X	X		X	Tolerates High pH
Hickory *(Carya spp.)*	X	X	Fair	X		X	X	
Honeylocust *(Gleditsia tricanthos)*	X	X	Good	X	X		X	Choose thornless variety
Mulberry *(Morus spp.)*	X	X	Excel.		X	X	X	Wood hard and durable
Osage-Orange *(Maclura pomifera)*	X		Excel.	X			X	Drought tolerant, excel. fuel wood
Pin Oak *(Quercus palustris)*	X	X	Good				X	Retains lower branches
Red Maple *(Acer rubrum)*	X	X	Good	X	X	X		
Red Oak *(Quercus rubra)*	X		Fair	X			X	Fast growing oak
Siberian Elm *(Ulmus pumila)*	X	X	Good		X			Drought tolerant
Silver Maple *(Acer saccharinum)*		X	Poor	X	X	X	X	Flood tolerant

[1]*Information sources: Dirr (1990), Burns & Honkala (1990b)*
[2]*Value as a windbreak species*
[3]*Wood products = timber, veneer, posts & poles*
[4]*Fast growing species for fuel wood & chips*
[5]*Includes: fruits & nuts, jellies, jams, wine, maple syrup, & pollen for bees (honey)*

Table 3c — Shrubs and small trees for use in agroforestry systems in the northern Great Plains[1].

Common name/species	Upland	Bottom Land	Protection Value[2]	Wildlife Food	Wildlife Habitat	Food Products[3]	Comments
American Plum *(Prunus americana)*	X	X	Good	X	X	X	Spreads by suckering
Autumn-Olive *(Eleagnus umbellata)*	X	X	Good	X	X	X	Fixes nitrogen
Buckthorn *(Rhamnus cathartica)*	X		Good	X	X		
Buffaloberry *(Shepherdia argentia)*	X	X	Good	X	X	X	Tolerates alkaline soils
Chokecherry *(Prunus virginiana)*	X		Good	X	X	X	Well drained sites
Crabapple *(Malus spp.)*	X	X	Fair	X		X	
Elderberry *(Sambucus canadensis)*		X	Fair	X	X	X	Rich moist lowlands
Golden Currant *(Ribes aureum)*	X	X	Fair		X	X	Tolerates a range of sites
Hazelnut *(Corylus spp.)*	X		Good	X	X	X	Used for oils and flavorings
Honeysuckle *(Lonicera spp.)*	X		Good	X	X	X	Susceptible to aphids
Lilac *(Syringa vulgaris)*	X		Good		X		Full sunlight, susceptible to borers
Nanking Cherry *(Prunus tomentosa)*	X		Good	X	X	X	
Peashrub *(Caragana spp.)*	X	X	Excel.		X		Tolerates poor dry soils
Russian-Olive *(Eleagnus angustifolia)*	X	X	Good	X	X		Fixes nitrogen, susceptible to canker
W. Sandcherry *(Prunus besseyi)*	X		Good	X	X	X	Low growing
Serviceberry *(Amelanchier spp.)*	X		Good	X	X	X	
Sumac *(Rhus spp.)*	X		Good	X	X	X	Tolerates dry and alkaline soils

[1] *Information sources: Dirr (1990)*
[2] *Value as a windbreak species*
[3] *Includes: fruits and nuts, jellies, jams, wine*

autumn-olive (*Eleagnus umbellata*), and American plum (*Prunus americana*) are especially attractive to bees and can be included in the windbreak as bee forage to produce honeys with distinctive flavors.

Sugar maple (*Acer saccharum*), the preferred species for the production of maple syrup, is restricted to the eastern edge of the Great Plains. In contrast, boxelder or Manitoba maple (*Acer negundo*) can be found across the region in fence rows, riparian zones and windbreaks. It produces sap with a sugar content of 1.6 to 3.6 percent which can be boiled down to produce syrup with an acceptable flavor (Fox 1992).

A windbreak can also be used as a seed orchard for the production of selected or superior genotypes. Careful species selection at the time of planting may provide future opportunities for the collection of seed for sale to wholesale nurseries. For example, the Nebraska Forest Service currently buys seed from American plum, chokecherry (*Prunus virginiana*), Russian olive (*Eleagnus angustifolia*), bur oak (*Quercus macrocarpa*), black walnut (*Juglans nigra*), sumac (*Rhus aromatica*) and American elderberry (*Sambucus canadensis*) at prices ranging from $0.15 to $25.00 per pound (Bill Lovett, personal communication).

Windbreaks as Crops

Windbreaks can be designed and managed to provide an assortment of wood products while continuing to provide protection for adjacent crops. These types of windbreaks generally require intensive management, and special care must be given to maintain the overall structure of the windbreak since it is this structure that reduces wind speed.

The management of existing multiple row windbreaks (10 rows or more) for timber or fuel wood is similar to that of a small woodlot. In most cases, current species are not the high value timber species, but larger trees such as poplar (*Populus* sp.), ash (*Fraxinus* sp.), and elm (*Ulmus* sp.) can provide lumber for crates and pallets or may be sawn for on-farm use. Cedar (*Juniperus*) and osage-orange (*Maclura pomifera*) are resistant to decay and provide excellent posts and poles. Cedar may be chipped for animal bedding and brings a premium when packaged for the small animal or pet market. Other types of wood chips are used for livestock bedding, landscape and garden mulches, and fuel. In areas near urban markets, firewood can provide additional income.

If the goal is to produce high-quality hardwoods such as walnut or oak, these species will need to be included in the initial windbreak planting design. These types of systems produce nuts within 10 to 20 years and timber within 50 to 75 years. One drawback of these species is that to gain high-quality timber, pruning of the lower branches is required. This decreases nut production and reduces the protective value of the barrier. Protection can be enhanced by including a shrub row in the windbreak to increase density near the ground. Another limitation is the sensitivity of these species to herbicides used in agricultural operations, which may reduce tree growth and quality.

Christmas trees or nursery stock production offer short-term products which also provide wind protection. A system of alternating tree rows with other specialty crops between the tree rows offers the possibility of two types of crops with different cultural schedules. In addition, the trees offer protection for the wind-sensitive crop and provide an economic return when they are sold. These types of systems are very specialized and labor intensive. They require specialized equipment, extensive business skills and a good understanding of marketing; however, by a series of plantings and harvests, both wind protection and tree crops can be realized from an intensively managed agroforestry system.

Protection Benefits

In addition to the obvious protection benefits of windbreaks to crop production, several other aspects of wind protection can provide economic returns. Windbreaks provide outstanding habitat for various kinds of wildlife. The inclusion of woody habitat in agricultural landscapes increases the diversity of bird, mammal, insect, and microbial species which inhabit an area. This greater diversity in both plant and animal species has the potential to increase natural control of pest outbreaks and contribute to the ecological stability of the agricultural ecosystem. With careful planning and management, windbreaks can improve economic return by enhancing insect predators and reducing the need for pesticides.

While some benefits of wildlife are difficult to measure, others are more easily quantifiable. In the United States, billions of dollars are spent each year on wildlife-related recreational activities (USFWS 1993). In the Great Plains, hunting upland game birds is usually more successful in areas with windbreaks or other woody plantings (Lyon 1961). In a Kansas study, over $30 million in annual expenditures were attributed to hunting in and adjacent to windbreaks (Cable and Cook 1990). As urban pressures increase, land available for hunting will continue to decrease. Landowners willing to provide access to their land for hunting or other recreational activities may be able to charge an access fee, providing an economic return.

Summary

Windbreaks provide wind protection for crops and soils, improve crop yield and quality, and increase net economic return. Including selected woody species as part of a windbreak system can provide additional products (timber, fruits and nuts, nursery materials) which can increase the total economic return. The addition of woody species to the agricultural landscape provides habitat for many natural predators, reducing the need for pesticides, and adds other sources of income from wildlife-related activities.

The integration of agroforestry practices into sustainable agricultural systems can provide many rewards. It requires, however, careful consideration of all aspects of the operation, an understanding of basic ecological principles and a working knowledge of local conditions and markets.

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Ecolotree™ Buffers: Non-Point Pollution Control Using Agroforestry Technology[1]

Dr. Louis A. Licht[2]

Abstract — The Pacific Northwest offers a dramatic range of landscapes and land uses in which agroforestry may further economic and resource conservation goals. Agroforestry practices common here are forest grazing, windbreaks and shelterbelts, and harvest of special forest products. Windbreaks and shelterbelts are vastly underutilized. Cultivation of hybrid poplar and woody riparian buffer strips hold untapped promise for improving landscape sustainability. Silvopasture and enrichment plantings are not widely known, but may become so in the future.

The greatest potential for realizing the full benefits of agroforestry exist on private land due to landowner's greater decision making flexibility. We see lack of technical assistance and demonstration areas as the greatest obstacles to increasing landowner's use of agroforestry. A number of economic factors will affect the future use of agroforestry. Scarce research *within the region* on use of woody riparian buffer strips is a cause for concern as results extrapolated from other regions may not represent Northwest conditions. Riparian restoration is a priority on public and private lands, therefore, developing this research base is a high priority. Hybrid poplar will probably become increasingly common in agricultural landscapes, and hard data are needed on the environmental influence of these plantations.

Buffer Research Results

Agricultural non-point nitrate nitrogen, herbicides, and sediment enter surface waters by runoff and subsurface drainage and represent the largest source of water contamination in EPA Regions 7 and 8. Riparian buffers incorporating hybrid Populus spp. (poplar) trees as a water treatment technology for non-point agricultural pollution removal began in 1988 at the University of Iowa. The resulting technique, named the Ecolotree Buffer (Buffer), combines water contaminant removal with commodity production and harvest. These concepts were named Ecolotree to differentiate this design from other grass or tree buffer designs developed by the USDA Soil Conservation Service (SCS) and funded as a Best Management Practice (BMP) through cost share programs.

The SCS BMP for riparian buffers requires a minimum 36.4 m (120 ft) wide stream bank edge normally growing mixed deciduous hardwoods with a 40+ year harvest cycle; this BMP requires 30 acres of crop land per mile of buffered stream and contributes little to short-term farm profitability.

In contrast, the Ecolotree Buffer grows four rows of Populus spp. (poplar) trees and grass understory in only a 10 meter (33 ft) wide stream bank corridor; this concept requires approximately 8 acres of land per mile of buffered stream reach and produces harvestable value within two years. The Buffer uses less land, grows more harvestable biomass faster, adapts to row-crop mechanization, permits alternative planting strategies, grows a new commodity crop with many potential markets, diversifies wildlife habitat, and

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reduces water/wind erosion. With an understory that includes native forbes and grasses, the Ecolotree Buffer can rejuvenate a strategic field edge from an annually plowed monoculture to a perennial polyculture with greater diversity and maturity.

Two adjacent agricultural watersheds at Amana IA have been instrumented to measure and sample stream flows. One stream was completely buffered with approximately 15,000 trees in 1992; the other watershed is unbuffered. Both watersheds are cropped with corn and soybeans.

The principle results from the 1993 growing season monitored from July through November include:

- The daily average nitrate-nitrogen concentration in the runoff water leaving the buffered watershed never exceeded the EPA drinking water standard of 10 mg nitrate nitrogen per liter in the 1993 growing season. The daily average nitrate-nitrogen concentration in the runoff water leaving the unbuffered watershed exceeded the EPA drinking water standard on forty (40) days between July 10 and August 30, 1993.
- For the 1993 monitoring season, the runoff water leaving the buffered watershed had 68% less nitrate-nitrogen mass per cropped acre than the unbuffered watershed.
- For the 1993 monitoring season, the runoff water leaving the buffered stream had 75% less sediment mass per cropped acre than the unbuffered watershed.

Buffer Implementation Strategy

Assuming annual crops will always be required for food, forage, and industrial feed stocks, a sustainable agriculture will include buffers strategically laced across the annually tilled landscape. These buffers will create the maximum value from the harvested crop and the ecosystem stability.

Strategic buffer strips mean placing trees and grasses at the following locations:

- Riparian Buffers - ranging from 2 to 35 meters (6 - 120 feet) wide planted next to streams to act as the final sediment, organic pesticide, and fertilizer filter. If 80% of all Iowa streams were buffered with 4-row poplar buffers, it would require an estimated 600,000 acres of land.
- Livestock Manure Buffers - ranging from 10 to 60 meters (33 - 200 feet) wide planted down gradient of livestock housing to act as the final manure filter odor trap, and shelter windbreak.
- Field Terrace Buffers - ranging from 1 to 3 meters (3 - 10 feet) wide planted on the field contour instead of more expensive graded terraces can intercept runoff and act as a midfield filter that redistributes and slows eroding water and shelters downwind crops. A mile long, 2-row terrace buffer would take 1.2 acres of land.
- Water Supply Buffers - surrounding well heads and infiltration galleries that supply water for small and large communities.
- Waste Water Buffers - that provide the final filter for removing nutrients (nitrogen and phosphorus) and organic matter before urban waste water finally enters a stream.

Buffer Research Results Summary

Riparian buffer research incorporating hybrid Populus spp. (poplar) trees as a water treatment technology for pesticide, toxic organic chemical, and nutrient removal began in 1988 at the University of Iowa (Licht, 1990). The Ecolotree Buffer incorporates the buffer installation and management techniques developed from this prototype work. These concepts were named to differentiate this design from other grass or mixed tree buffer designs developed by the Soil Conservation Service and funded under Best Management Practices. The Ecolotree design concepts are summarily documented in the following literature:

1. Drinking water quality degrades from nitrate-nitrogen, pesticides, and sediment draining from annually tilled row-crop agriculture, as researched by Alberts et al, 1978; Baker, 1980; Baker and Johnson, 1976; Blackmer et al, 1989; Burwell et al, 1977;

CAST, 1985; Kramer et al, 1989; NRC, 1978; and Tisdale, 1975.

2. Nitrate-nitrogen removal from the soil pore water via plant root uptake and metabolism has been documented by Licht, 1990; Licht 1991, Licht 1992; Barber, 1984; Glass, 1989; Gregory, 1987; Haynes, 1986; and Lewis, 1986.
3. Poplar trees survive and thrive in the riparian environment, and influence the water flux and nutrient dynamics which impact water quality, as documented by Licht, 1993; Bowmer, 1981; Christ et al, 1983; Dickman, 1983; Ek, 1983; Isebrands, 1983; Kawase, 1981; Mitsch, 1986; and Zavitkovshi, 1983.
4. Non-tilled riparian buffers planted with perennial trees improve surface water quality by intercepting soluble fertilizer and sediment eroding from annual tillage, as documented by Licht, 1990, Licht, 1991, Licht, 1992, Cooper et al, 1986; Dillaha, 1989; Jacobs and Gilliam, 1985; Lowrance, 1984, Schlosser and Karr, 1989; USDA/SCS, 1988.
5. Poplar roots remove virtually all soluble atrazine and other soluble organic molecules from soil pore water; the plant thrives at herbicide concentrations normally found in water running off corn fields. This has been documented by Nair, 1991; Nair et al, 1993; McFarlane, 1990.
6. Plant-based water treatment systems can be engineered for water quality improvement for nonpoint and point source water discharge, as documented by Crites and Reed, 1986; Overcash and Pal, 1981; U. S. EPA, 1981; Urie, 1987.

Ecolotree Buffer Results Summary

Results from the 1993 growing season have been submitted in an invited, peer-reviewed paper for National Geographic for April 1994 publication.

In-Buffer Ground Water Quality Improvement

The original buffer was designed and installed to control agricultural nonpoint nitrate-nitrogen leaking from fields to drainages beginning in 1986 at The University of Iowa. Data collected from laboratory, greenhouse, field plots, and full-scale watersheds have been synthesized into a set of operational techniques called the Ecolotree Buffer (Buffer). The name is trademarked to distinguish this concept from other grass or mixed-tree buffers. The buffer was designed to include densely planted, deep rooting trees for structure on narrow 2 m to 10 m (6 ft to 33 ft) - wide strips. In 1988, the buffer prototype installed at Amana, IA measured 120 m (400 ft) long, 5 m (16 ft) wide riparian buffer subdivided into plots containing 1600 trees.

The field work, supplemented by greenhouse tree experimentation, derived the basic relationships between nitrogen uptake, tree growth, root growth, carbon sequestration, and water uptake (Licht, 1990). Ground water was sampled biweekly between June 17 and Sept. 27, 1990 from piezometers located 2 meters upgrade from the tree buffer, midbuffer, and 2 meters downgrade. These buffer plots effectively removed nitrate-nitrogen seeping from upgradient corn fields to downgradient streams in the near surface ground water (Figure 1).

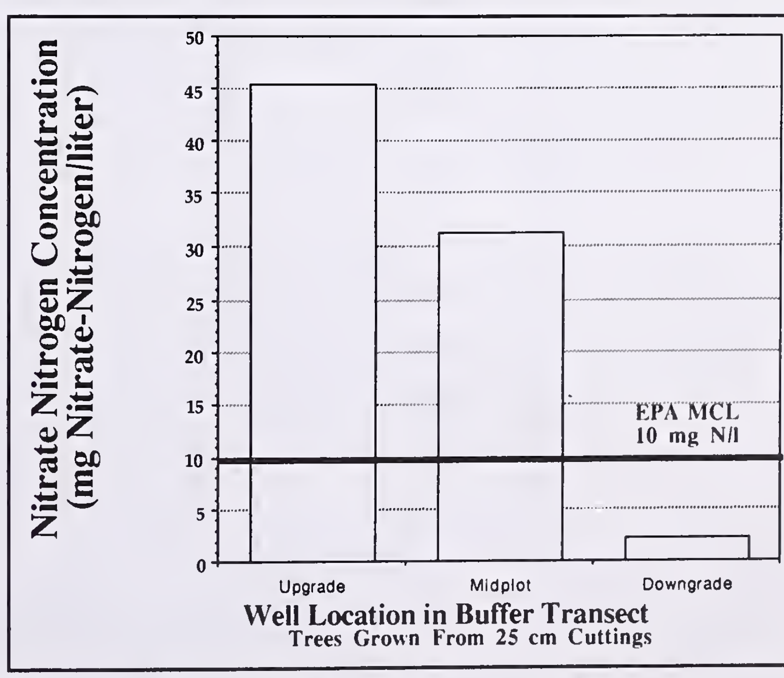

Figure 1 — Mean nitrate-nitrogen concentrations in near-surface ground water for third-year rising riparian Poplar buffer transects bordering row-cropped fields, Amana, Iowa, 1990.

In-Stream Impacts from Watershed-Scale Buffers

Water quality research expanded in 1991 to a paired agricultural watershed study; this field laboratory was made possible by funds from the USDA Forest Service, Center for Global and Regional Environmental Research, The University of Iowa, and US EPA.

Table 1 summarizes the field statistics for the site. Watershed 1 contains 103 acres with 80 acres in cropland; it is 37% the size of the 283 acre Watershed 3 which has 174 acres in cropland. Watershed 1 has no buffer along its first-order stream; crops are planted up to the stream bank. Watershed 3 has a first-order stream bordered on both sides by a four row riparian buffer containing 15,000 poplar trees. Amana Farms, the land manager, tills and plants annual crops using modern technology. Instrumentation necessary to measure nitrate-nitrogen, herbicide, sediment, and flow in the stream and the elevation and nitrate-nitrogen in near-surface ground water has been installed.

Table 1 — Land use on Amana watershed research site.

Land Useage	Watershed 1	Watershed 3
Mature Woodland	22	87
Conservation Reserve in Trees	0	19
Roads and Buildings	1	3.2
Farmed Cropland**	80	174
Total	**103**	**283**
**Cropland '93 Planting		
Corn-Soybean	80	135
Hay	0	34
Tree/Grass Buffer	0	5

Sediment, the soil washed into the stream and deposited elsewhere in the watershed, is the single greatest surface water contaminant leaving agricultural land. Annual tillage and weed control leaves the soil vulnerable to dislodging and suspension by precipitation, especially when the soils are saturated and unprotected by plant canopy. In addition, cropping patterns such as corn following soybeans in the crop rotation, create greater opportunity for erosion due to low amounts of crop residue on the field surface. Field slope, which influences the velocity and momentum of the runoff water, is greater on Watershed 1 and contributes to greater erosion.

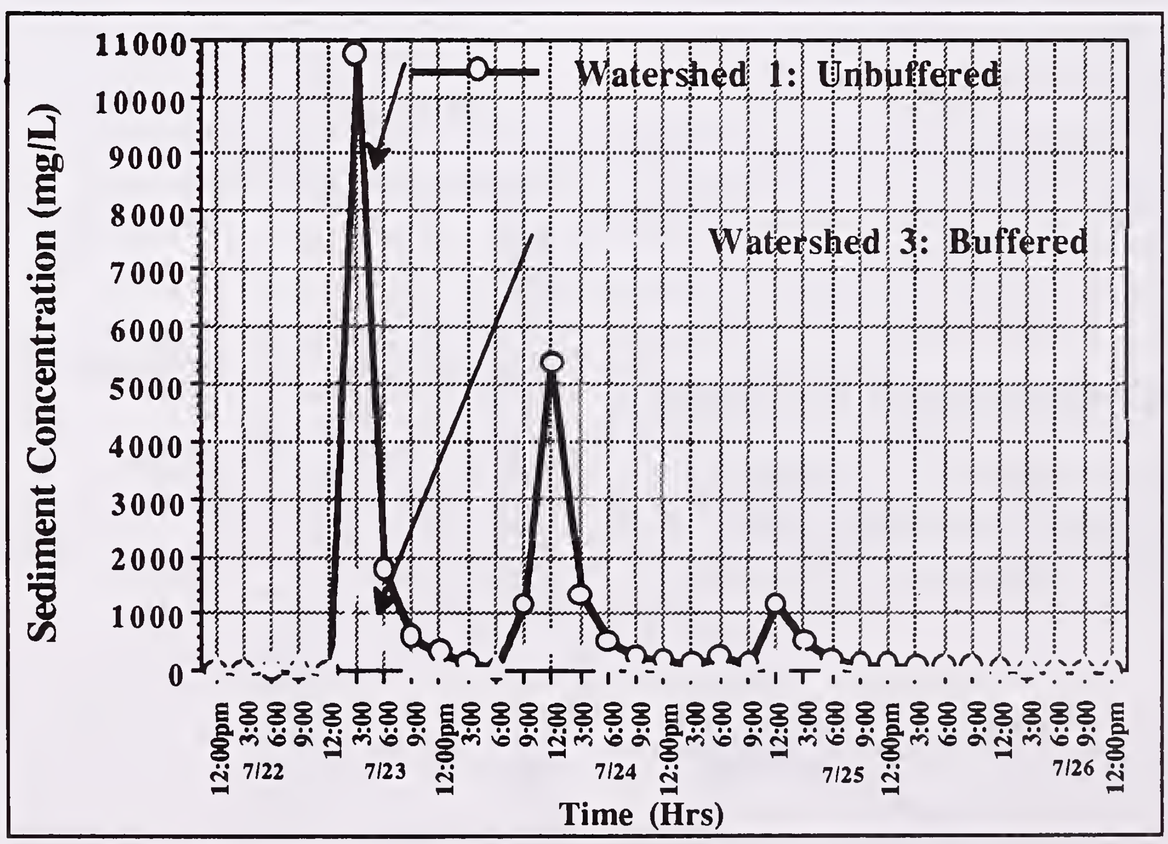

Figure 2 — Sediment concentration from watersheds, Amana, Iowa July 22-26, 1993.

The sediment loss data is summarized in Table 2. During the three hour peak flow on July 23, the runoff from the buffered Watershed 3 averaged 1,700 mg sediment/liter (ppm) (Figure 2). The maximum sediment concentration in the unbuffered Watershed 1 runoff was 647% greater, exceeding 11,000 mg sediment/liter (ppm). The runoff draining Watershed 1 was noticeably more laden with soil. The adjacent stream bank had large drifts of deposited soil from the summer rain, and there are obvious sediment deposits in Lily Lake located at the bottom of the watershed.

The total mass of soil leaving Watershed 1 is approximately 124,571 kg or 274,000 pounds (Figure 3). The total mass of soil in the runoff from Watershed 3 is approximately 44,828 kg or 98,622 pounds. Assuming a bulk density of 100 pounds of soil per cubic foot, this represents 2740 ft^3 and 986 ft^3 of soil from Watersheds 1 and 3, respectively.

Table 2 — Sediment loss from watersheds, measured at the stream outlet draining to Lily Lake, Amana, Iowa July 22-26, 1993.

Total Sediment Loss in:	Watershed 1 Un-buffered	Watershed 3 Tree Buffered
• mg/L	11,000	1,700
• kg	124,571	44,828
• lb	274,000	98,622
• ft^3	2740	986
Average Sediment Loss per Cropped Acre	**Watershed 1 Un-buffered**	**Watershed 3 Tree Buffered**
• kg	1549	258
• lb	3408	568
• ft^3	34	6

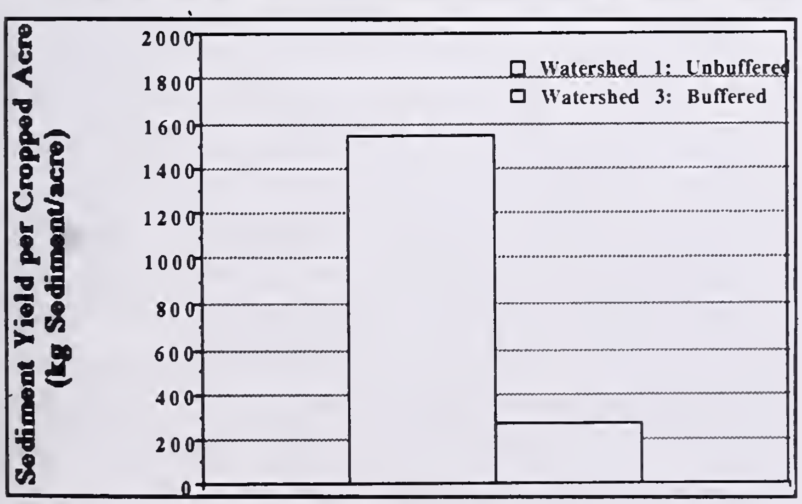

Figure 3 — Average sediment yield per acre of row-cropped land from watersheds, Amana, Iowa July 22-26, 1993.

The total mass of soil loss per row-cropped acre for Watershed 1 is approximately 1549 kg or 3408 pounds (Figure 3). The total mass of soil per row-cropped acre in the runoff from Watershed 3 is approximately 258 kg or 568 pounds. Assuming a bulk density of 100 pounds of soil per cubic foot, this represents 34 ft^3 and 6 ft^3 of soil from Watersheds 1 and 3 respectively. This is a 77.8% reduction of sediment per acre of annually cropped land.

Nitrate Nitrogen

With the monitoring system it is now possible to compare the nitrate-nitrogen in the streams. In water drainage from Watershed 1 and Watershed 3 (Figure 4), only unbuffered Watershed 1 has nitrate concentrations that exceed the EPA Maximum Contaminant Limit of 10 mg nitrate-N/liter. During the rainfall events, the nitrate concentration is diluted with the additional runoff.

The total mass of nitrate-nitrogen loss per row-cropped acre in Watershed 1 is approximately 1.69 kg or 3.72 pounds (Figure 5). The total mass of nitrate-nitrogen per row-cropped acre in the runoff from Watershed 3 is approximately 0.52 kg or 1.15 pounds. This is a 69% reduction of nitrate-nitrogen per acre of annually cropped land.

The mass of nitrate-nitrogen was approximately 136 kg from Watershed 1 and 91 kg from Watershed 3 during the four day monitoring period. This is enough nitrate nitrogen to contaminate 22,700,000 liters of water, approximately 6,000,000 gallons, to the 10 mg nitrate-N/liter MCL.

It is concluded that there is a very significant difference between the sediment and nitrate nitrogen concentrations in the streams draining adjacent watersheds. The buffer is the single most important interceptor of the overland flow and removal of sediment. The tree roots remove the subsurface nitrate nitrogen seeping to the creek.

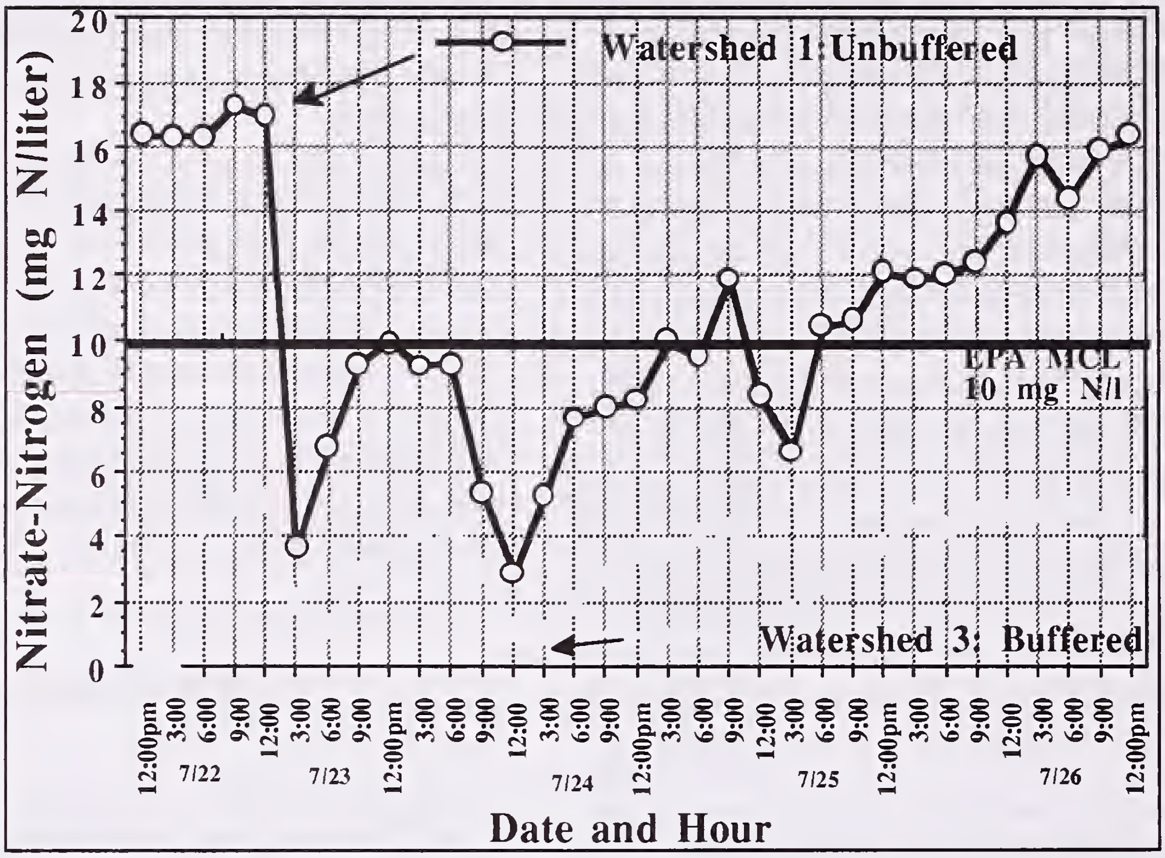

Figure 4 — Nitrate nitrogen concentration in the runoff from paired watersheds at Amana, Iowa July 22-26, 1993.

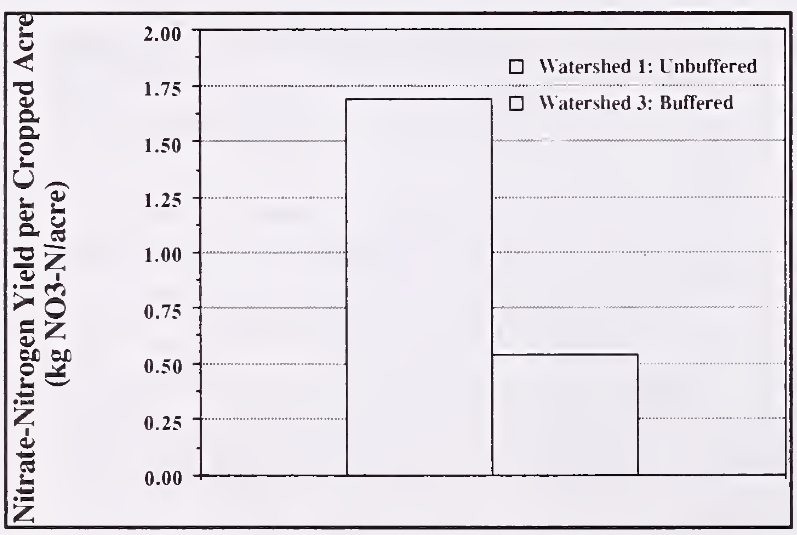

Figure 5 — Nitrate nitrogen yield per cropped acre from paired watersheds at Amana, Iowa, July 22-26, 1993.

Additional quantification of the buffer contribution to these phenomena will be developed by future use of the WEPP model.

Rationale and Significance

The rationale pursued in this research fundamentally changes the way cornbelt farmers manage their land. In the cornbelt, the agricultural ecosystem is eroding away due to annual tillage from annual corn and soybean cropping. The Ecolotree Buffer design makes it possible to grow a new commodity crop from perennial plants that requires few pesticides, that scavenges excess nutrients, and that stabilize Iowa's eroding soils.

Nonpoint source contamination of surface water supplies by normal agricultural practices is the source of pollutants that most often exceed the EPA's Maximum Contaminant Levels in agricultural regions. This project will begin a modeling effort to define new cropping techniques, ultimately defining an approved Best Management Practice (BMP) for use by farmers and eligible for the U.S. Department of Agriculture cost-sharing programs. Rather than growing annually tilled cereal grains fencerow-to-fencerow and creek-to-creek, the Ecolotree Buffer concept laces the landscape with narrow strips of perennial trees/grass. A skinny buffer that grows tall trees and forbs creates a more mature ecosystem; it can develop soil structure, deep plant root systems, dense surface stem structure, and a diversity of life.

A landscape with strategic strips of mature buffer ecosystems would help stabilize adjacent

juvenile, highly disturbed, annually-tilled ecosystems. A buffer acts as an edge; it's basic design is different than a field engineered for annual plants, spaced in rows, normally planted in fields with straight edges. A buffer bends to fit the lay of the land. It can lay adjacent to meandering creeks, contour on a hillside, border a feedlot, or covering a well head.

Plants contain 16 essential elements. In any ecosystem, the cycles of these elements and water are greatly affected by the plant species, age, density, and growth rate. A perennial buffer has a different ecology of annually disturbed corn field. The Ecolotree Buffer is a transitional cropping plan as the land reverts from annual crops, through the pioneering perennial plant phase, then on to a prairie or forest ecosystem. Fast growing *Populus spp.* (poplar) and *Salix* (willow) trees provide most of the early vertical structure and water quality impacts. Native prairie species are being planted in the understory, aggressive natural annual grasses and forbs (normally called weeds), are mowed and not managed with organo-chlorine containing herbicides.

With tree buffers, the rural economy would be more diverse with less dependence on the carbohydrate and protein markets. Biomass fuel from perennials would provide for local and regional energy needs; this crop would be in competition with fossil fuels now imported to much of the midwest. Other uses of fiber for chemical feedstocks, paper pulps, and construction material still remove the land from over-produced corn and soybeans.

A new commodity crop that is a perennial, that economically grows an energy commodity - not a food commodity, and that diversifies the economy with new products locally processed and consumed would have a ripple effect through society. It would give regulatory agencies a new piece in the puzzle to meet their various missions of market support, water/air quality improvement, social welfare maintenance, or maintaining wildlife populations. The holistic end result of this work is an agricultural ecosystem with more diversity and that offers future generations more options in meeting the challenges of their era. This concept is timely because major crop diversion programs such as USDA's Conservation Reserve Program will expire in 1997; alternative cropping guidelines will be considered in the 1995 Farm Bill.

Appendix 1 contains an editorial titled "Tree Buffers — After the Fall of the Conservation Reserve Program", Licht 1994, which summarizes this situation.

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Agroforestry as a Method of Salt and Selenium Management on Irrigated Land[1]

V. Cervinka, C. Finch, G. Jorgensen, F. Karajeh, M. Martin, F. Menezes, and K. Tanji[2]

Abstract — History provides examples of the decline of many civilizations when the productivity of agriculture was destroyed due to salt build-up on irrigated farmland. Irrigation water contains salt which accumulates in the soil profile. If no outlet exists to discharge this salt into rivers and/or oceans, the gradual increase of soil salinity reduces the crop yields. This process is now occurring on irrigated land in the west side of the San Joaquin Valley. Soil salinity levels, in combination with increasing selenium concentrations, threaten the economic and ecological viability of the whole region.

Introduction

In 1985 and 1986 several growers, with the support of the Westside Resource Conservation District (WRCD), California Department of Food and Agriculture (CDFA), and USDA-Soil Conservation Service, began to explore the management of salt and selenium using agroforestry as a method for mitigating salinity and selenium problems. Since then, the agroforestry program has conducted numerous studies in participation with the University of California, Davis; California State University, Fresno; Department of Fish and Game; and University of Arizona, Tucson. Agroforestry program funding has been provided by several agencies, including the Bureau of Reclamation, USDA-Soil Conservation Service, Department of Water Resources, California Department of Food and Agriculture, State Water Resources Control Board, Resources Agency, and Westlands Water District.

This report will (1) describe Agroforestry for Sustainable Agriculture as a method of managing salt and selenium, (2) discuss the results of seven years of experience, and (3) evaluate the prospects of using agroforestry as a basic farming method for salt mining on irrigated land in the San Joaquin Valley.

Definition of Agroforestry for Sustainable Agriculture

Agroforestry for Sustainable Agriculture, as developed in California, is a bio-engineering system to mine salt (and selenium) on irrigated farmland. It operates on the principle of reusing water to irrigate crops of continuously increasing salt tolerance. When the salt concentration is reaching levels harmful to highly salt tolerant crops, the final amount of reused water is discharged into a solar evaporator for salt crystallization and removal. The system is based upon the principle that drainage water is a resource, rather than a waste, and its management results in mining of salt from irrigated land. By removing salt and selenium, the system enhances the environmental quality of both farming and wildlife habitats.

Agroforestry - System Description

Drainage water from salt sensitive crops (e.g., vegetables) is reused to irrigate crops with moderate salt sensitivity (e.g., cotton), then reused a

[1]Paper presented at the Agroforestry and Sustainable Systems Symposium, Fort Collins, CO, August 7-10, 1994.

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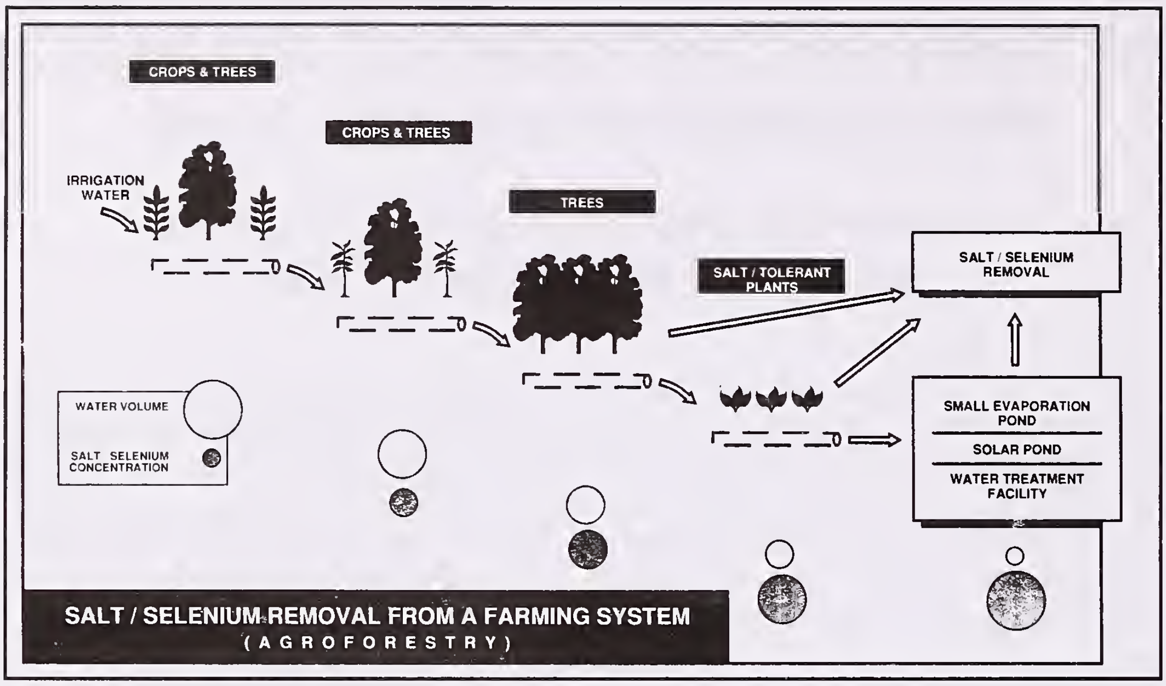

Figure 1 — Operational scheme of an agroforestry system. Salt/Selenium removal from a farming system.

second time to irrigate salt tolerant crops (e.g., eucalyptus trees), and it is again reused to irrigate crops of high salt tolerance (e.g., atriplex). At this point, the salt concentration in the final and reduced volume of drainage water may reach levels beyond the salinity tolerance limits for any crops, and this water is then discharged into a solar evaporator. The operational scheme of an agroforestry system is illustrated in Figure 1.

The quantity of drainage water discharged into the solar evaporator is correlated with daily evaporation rates. This prevents any major ponding of water. Thus, the solar evaporator does not attract wildlife. The environmental risk of transferring selenium into the wildlife food chain is controlled.

Salt and selenium management is the main reason for reusing drainage water to irrigate high salt tolerance crops; but these crops also offer an opportunity for economic return by marketing them as energy biomass, industrial materials, and livestock feed. The development of uses and markets for mined salt and selenium will enhance the economic viability of agroforestry. Work on the latter is in progress.

An agroforestry system should be well designed and operated. Water applications to salt tolerant crops need to be controlled to maximize water use with respect to soil or biological constraints associated with farming, as well as climatological conditions. The relative areas of trees, high salt tolerant crops and a solar evaporator are a function of water flows moving salt through the agroforestry system.

Table 1 — Major components of an agroforestry system for sustainable agriculture.

Salt management	• crystallization • disposal/marketing
Selenium management	• uptake by trees/plants • volatilization • transfer by feeding halophytes • transfer by salt marketing
Halophytes	• selection • drainage water reuse • field operations • utilization
Salt tolerant trees	• selection • drainage water reuse • field operations • utilization
Water management	• reuse • interception • uptake from shallow water tables • salt/water balance
Wildlife habitat	• selenium management

Economics of agroforestry as a farming system

Agroforestry Program - Present Status

Agroforestry for Sustainable Agriculture is a system involving individual components of farm crop production which are designed and managed in a well balanced operation. The major components of the agroforestry system for sustainable agriculture are listed in Table 1.

The components function in an integrated way; the performance of a single component affects the overall effectiveness of the agroforestry system. To achieve a desirable input/output salt balance in farming on irrigated land, salt must be removed to sustain the high productivity of farming. Consequently, the discussion on the present status of the agroforestry program will start with the management of salt.

Salt Disposal

The San Joaquin Valley options available for salt (in drain water or crystallized salt) disposal include:

- discharge into the ocean
- discharge into the San Joaquin River
- mining and discharge into a toxic waste disposal site
- mining and storage on farms
- use in animal/wildlife feeding
- use as an industrial feedstock

The discharge of salt into the ocean would be a technically sound way of salt disposal; however, due to the combination of economic and political factors, it is not feasible at this time.

The discharge of salt in the San Joaquin River is practiced in the northern areas of the valley. The disposal of salt is (and will continue to be) regulated. The use of agroforestry practices in this area would reduce the volume of drainage water, and, thus provide for a better management (and timeliness) of its discharges into the river.

The discharge of salt into a toxic waste disposal site is technically feasible; but it is costly (more than $100 per ton — Kettleman Hills Treatment and Disposal Center, personal communication), and it would be unrealistic to assume that the capacity of disposal sites would be sufficient for all the salt harvested during the next 20 or 200 years.

As has already been demonstrated, the mining of salt in an agroforestry system is feasible. The economic uses of mined salt and selenium remain to be developed; but, the temporary storage of mined salt on farms could be considered until uses and markets are developed. It is estimated that a solar evaporator of only 0.69 ha (1.72 acres) is required to mine salt from a farm of 259 ha (640 acres); the solar evaporator represents only 0.26 percent of farmed area. The layer of crystallized salt is estimated at about 60 to 70 mm per year (2.4 to 2.8 inches).

The U.S. salt market is divided in the following way:

• livestock feed	10 percent
• food consumption/processing	20
• industrial use	70

The use of harvested salt in feeding livestock and wildlife is being evaluated. Funds provided by the Bureau of Reclamation for an experimental project will support research in this area. Large areas of the Western states are selenium deficient, with negative effects upon cattle and wildlife health. A study on atriplex forage, conducted in cooperation with California State University, Fresno, California Agriculture Technology Institute and supported by funds provided by the Department of Water Resources, indicated the possibility of transferring selenium, uptaken by salt tolerant crops (forage), through cattle or sheep feeding. The benefits of transferring selenium with salt to cattle (and wildlife) is a major focus of investigation.

The composition of crystallized salt is:

• Calcium	0.65	%
• Sodium	23.50	%
• Potassium	0.01	%
• Carbonate	<0.001	%
• Bicarbonate	0.05	%
• Chloride	8.4	%
• Sulfate	56.70	%
• Boron	0.07	%
• Manganese	<1.00	mg/Kg
• Selenium	1.80	mg/Kg

- Arsenic <0.10 mg/Kg
- Lead <0.10 mg/Kg
- Molybdenum <10.00 mg/Kg

The main components of salt are sulfate and sodium. Presently, the potential industrial use of harvested salt is evaluated in the area of tile glazing. The U.S. Bureau of Mines has also advised the California Department of Food and Agriculture (CDFA) about the possibility of mixing ash from power plants with sodium sulfate to produce a composite material suitable for soil stabilization. California Department of Transportation (Caltrans), in cooperation with CDFA, will test this mix. The Salt Institute has been providing technical and marketing information. The California Integrated Waste Management Board has listed salt harvested on farms as material available for industrial uses, and the first inquiries have been received. The CDFA has established contact with major salt mining/processing companies. The possibility of marketing salt harvested on farms in the San Joaquin Valley is being investigated. The development of a utility value for harvested salt will require a major effort.

Salt Mining

Salt mining is performed through the process of continuously increasing salt concentration in the water reused to irrigate crops and trees of differentiated salt tolerance, and final salt crystallization in a solar evaporator. The solar evaporator was developed and tested at the Mendota experimental site. It consists of a leveled area covered with a plastic liner. During testing, drainage water (>EC 40) was discharged into this solar evaporator in small volumes correlated with daily evaporation rates. The evaporator was tested from May 1993 until October 1993, but it did not operate continuously because several changes were required, including the installation of a water filter, maintenance of the flow meter, operation of the timer, and valve adjustments. A salt layer of over 70 mm (2.8 inches) was created in deeper areas of the evaporator.

The size of the experimental solar evaporator is about 75 sq. m, (807 sq. feet) which is not adequate for evaporating all drainage water coming from the halophyte area of the experimental project. The design of the project will be changed for future experiments, and a solar evaporator of 1.3 ha (3.2 acres) will be established.

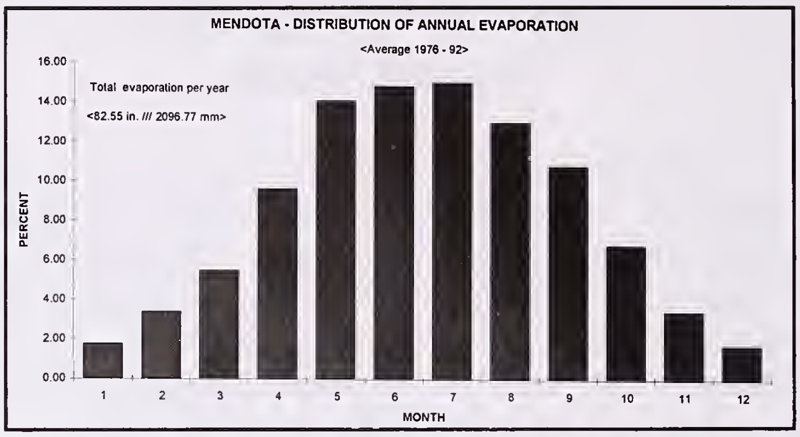

Figure 2 — Distribution of annual evaporation for the Mendota site.

The distribution of annual evaporation for the Mendota site is presented in Figure 2.

It is estimated that annual drain water evaporation from the solar evaporator will be about 1,360 mm (53.5 inches) per year, which is 65 percent of total annual evaporation.

The average thickness of crystallized salt in the solar evaporator is estimated, from data on water reuse, at about 60 to 70 mm (2.4 to 2.8 inches) per year. This calculation is based upon 685 t of salt from an area of 259 ha, at 1.5 t/cu.m., crystallized in a solar evaporator of .69 ha. The experimental data, from the operation of the solar evaporator in 1993, are correlated with this estimate.

Selenium Removal

The selenium balance in agroforestry systems will be studied in a comprehensive way. Up to now only separate methods of selenium removal by harvesting tree biomass or halophyte forage have been evaluated. See Table 2.

During the combustion of tree biomass, about 80 percent of fuel selenium was emitted in either the particulate phase or the exhaust gas phase (Happ).

Harvested halophytes were analyzed for selenium content (mg/kg):

- Atriplex .60 - 1.30
- Iodine bush .00 - 0.20
- Five hook bassia .30 - 1.45
- Jose tall wheatgrass .58 - 1.80

Cooperation has been established with UCD (Macy) on removal of selenium from concentrated drainage water. The electrical conductivity of this water is about EC 40, and its Se content about 0.6 mg/L. For comparison, the typical value of incoming drainage water into a tree plantation is about EC 10, with a Se content of about 0.3 mg/L (Tanji and Karajeh). The UCD, CDFA, and WRCD have submitted joint proposals to the Bureau of Reclamation and State Water Resources Control Board (SWRCB) to test a reactor for selenium removal as an integrated component for the agro-forestry system. The reactor would process drainage water flowing from highly salt tolerant crops (halophytes) to a solar evaporator.

Successful experiments were conducted on the transfer of selenium through harvesting halophytes and using this forage for cattle feeding (Frost). Similar experiments will also be conducted on the transfer of Se, harvested together with salt, as feed supplement for cattle and/or wildlife feeding in Selenium deficient areas. See Figure 3.

Table 2 — Selenium uptake (mg/kg) by three-year-old trees (Happ).

eucalyptus	primary wood	.080	.170
	leaf	.500	.900
casuarina	primary wood	.070	.116
	leaf	.570	1.000
athel	primary wood	1.060	
	leaf	2.570	3.570

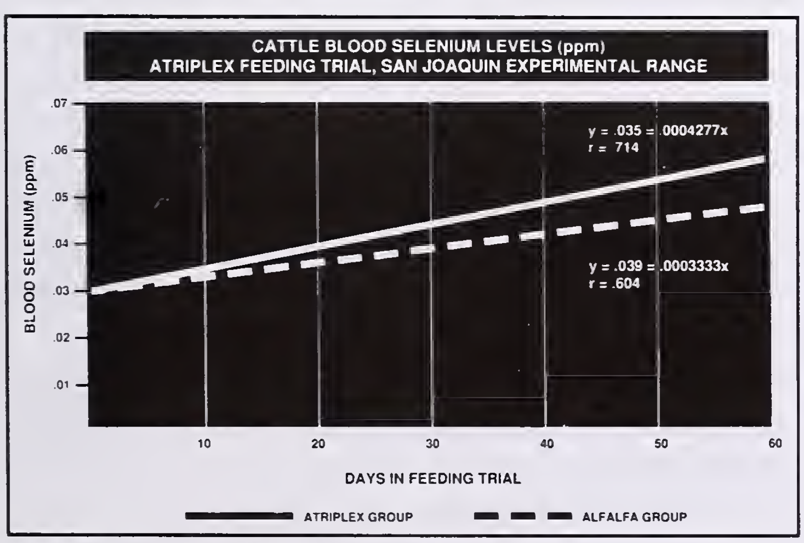

Figure 3 — Cattle blood selenium levels

Halophytes

Before drainage water is discharged into the solar evaporator, it is used to irrigate highly salt tolerant crops (halophytes). The selection of these crops was based on literature review, field evaluation trials, and survey of plants in salinity affected areas located in the San Joaquin Valley, Arizona, Australia, India and Pakistan. A list of plants was established, and it was submitted to the CDFA - Division of Plant Industry and to the Agricultural Commissioners of the County Departments of Agriculture for approval. A Memorandum of Understanding was signed among the CDFA - Division of Plant Industry, Agricultural Commissioner in Fresno County, Westside Resource Conservation District, and USDA-Soil Conservation Service to guarantee that the selected salt tolerant crops comply with basic requirements of biological safety with regards to conventional farm crops, i.e. the halophytes were not weed pests or hosts for insect vectors of viruses causing plant diseases.

Based upon on-going field evaluations in the San Joaquin Valley, the two most promising plants are Iodine bush *(Allenrolfea occidentalis)* and Quail bush *(Atriplex lentiformis)*. Field tests indicate that both plants tolerate drainage water above EC 40.

A second category of selected salt tolerant crops grows well being irrigated by drainage water from EC 20 to about EC 35.
These are included in the following table:

• Fivehook bassia	• Bassia hyssopifolia
• Saltgrass	• Dichtilis spicata
• Jose tall wheatgrass	• Agropyron elongatum
• Cordgrass	• Spartina gracilis
• Fat-hen	• Atriplex patula
• Red sage	• Kochia americana

Selected salt tolerant crops of the second category (EC 20 to 35) may be used in combination with trees (as understory plants) or as a crop on farms where drainage water coming off of conventional crops has EC 20 and above (high salinity for presently selected trees). A design proposal has been prepared for the Lost Hills Water District for the conversion of existing solar ponds into solar evaporators, and for using second cate-

gory salt tolerant crops for water reuse (EC above 20) to reduce the final volume of drainage water discharged.

Salt Tolerant Trees

Drainage water from moderately salt tolerant crops, at an EC 8 - 10, is reused to irrigate trees. Besides salt tolerance, trees are using a larger volume of water than halophytes, and, thus, are an important component of the system. Since 1985 over 600,000 trees have been planted for the management of salt on farms in the San Joaquin Valley. *Eucalyptus camaldulensis* is the main species planted. This type of eucalyptus was originally recommended by Australian scientists for its salt tolerance and higher water requirements. Originally, all eucalyptus seeds were imported from Australia and the quality of propagated trees was extremely diverse. To improve the quality of trees for agroforestry sites in the valley, a selection process started in 1987. The agroforestry program works closely with the California Eucalyptus Improvement Association (EIA) which has developed guidelines for the selection and propagation of superior trees. EIA assigned tree identification numbers within the range of 4500 to 4999 to the agroforestry program.

While the agroforestry program still imports selected seeds from Australia, trees planted since 1990 are mainly from California seed sources and/or plant materials. This has greatly improved the quality of planted trees.

Seed orchards have been established at farms near Five Points and Lemoore, and at the USDA-SCS Plant Material Center in Lockeford. Two tree sites near Mendota, California, have been planted in an experimental design to facilitate the evaluation of growth characteristics of selected trees.

Trees are being selected for salt tolerance, growth vigor, and frost tolerance. The freeze which occurred in December 1990 (temperature was -11.5 degrees C; 12 degrees F) clearly indicated the need to select trees to survive low temperatures. Tolerance for boron levels has also been added to the selection process.

The trees have been systematically evaluated each year, and selected ones have been chosen for tissue culture propagation. Plant tissues of 18 selected trees were given to Twyford Nursery for plant tissue propagation in 1990. The trees were planted on farms in Fresno, Kings, Tulare and Kern counties in 1991. The selection was narrowed for plantings in 1992 and 1993. At the present time, superior trees can be divided into two categories:

1) best trees 4543, 4544, and 4573

2) selected trees 4501, 4575, 4583, 4584, 4585, 4590, 4593

These trees have been selected for the 1994 planting season in the following quantities:

Table 3 — Number of trees and quantity that have been selected for the 1994 planting season.

Trees		Fresno	Tulare	Kern	Kings	Total
4543	eucalyptus	3078	304	660	2964	7006
4544	eucalyptus	3078	304	660	2964	7006
4573	eucalyptus	3420	304	680	2888	7292
4583	eucalyptus	76				76
4584	eucalyptus	798				798
4585	eucalyptus	798				798
4590	eucalyptus	722				722
Subtotal		**11970**	**912**	**2000**	**8816**	**23698**
C001	Casuarina	1100				1100
	Athel	3000				3000
Total		**16070**	**912**	**2000**	**8816**	**27798**

As Table 3 indicates, casuarina and athel trees will also be planted in 1994. The agroforestry program is oriented towards higher diversification of salt tolerant trees and crops planted for salt management.

Casuarina trees have been planted since 1985, but their performance has not always been satisfactory. *Casuarina Glauca* is not frost tolerant; it was damaged by frost in 1990, and did not recover. *Casuarina Cumminghamiana* has been frost damaged on several farms, and its recovery rate was lower than that of eucalyptus trees. Several individual trees performed very well under extremely difficult conditions (frost, salt, drought) at the Mendota site. Seeds and cuttings collected from these trees will be used for propagation of new trees to be planted in the 1994 season.

Athel *(Tamarix aphylla)* trees are well estab-

lished in the valley, being mainly used as windbreaks. They are salt tolerant and recover well from frost damage. Their utility value is inferior to eucalyptus trees. However, they may be beneficial on farms where salinity levels are above EC 20, and drainage water/salt management is the only objective in the development of an agroforestry system. Individual trees have been planted in 1991 and 1992, and they are performing extremely well. The agroforestry program considers the planting of about 3,000 athel trees in 1994.

Role of Salt Tolerant Trees and Plants

While water reuse is the main objective of water management in agroforestry systems, salt tolerant trees also are used to:

- intercept water seepage from water delivery canals
- intercept water flows from upland areas
- control high water tables

Trees have been planted for these purposes on several farms in the valley. Growers' experience with these clearly indicates the effect of trees on water interception and/or control of high water tables. Data will be developed on this use of trees.

Water and Salt Management

The process of salt mining from irrigated farmland involves the reuse of drainage water from salt tolerant crops (e.g., cotton, sugar beets, alfalfa) to irrigate salt tolerant trees. A portion of water applied to trees leaches salt from the soil profile. When it is again reused to irrigate highly salt tolerant crops (halophytes), the process of salt leaching also occurs in the halophyte field. The final, smaller volume of drainage water, with a high salt concentration, is discharged into a solar evaporator.

Based upon data collected during the ongoing experimental project at the Mendota site, a water management system can be calculated for a larger farm of 259 ha (640 acres). See Table 4.

Table 4 — Water management system.

Farm area	259	ha	640	ac
area of salt sensitive crops	**199**	**ha**	**492**	**ac**
irrigation rate	8	ML/ha/yr	31.5	in/yr
volume of irrigation water	1592	ML	1290	AF
leaching fraction	10	%	10	%
volume of drainage water	159.2	ML	129	AF
area of salt tolerant crops	**52**	**ha**	**128**	**ac**
irrigation rate	8	ML/ha/yr	31.5	in/yr
total irrigation water	416	ML	337	AF
added irrigation water	256.8	ML	208	AF
leaching fraction	20	%	20	%
volume of drainage water	83.2	ML	67	AF
area of salt tolerant trees	**5.2**	**ha**	**12.85**	**ac**
irrigation rate	16	ML/ha/yr	62.99	in/yr
volume of irrigation water	83.2	ML	67.39	AF
leaching fraction	25	%	25	%
volume of drainage water	20.8	ML	16.85	AF
area of halophytes	**1.73**	**ha**	**4.28**	**ac**
irrigation rate	12	ML/ha/yr	47.24	in/yr
volume of irrigation water	20.8	ML	16.85	AF
leaching fraction	45	%	45	%
volume of drainage water	9.36	ML	7.58	AF
area of solar evaporator	**0.69**	**ha**	**1.7**	**ac**

Using the foregoing parameters, the agroforestry system of water reuse reduces the volume of drainage water in these proportions:

	drainage water %	
• salt sensitive crops	100	----
• salt tolerant crops <*>	52	100
• salt tolerant trees	13	24
• halophytes	6	11

<*> irrigation water added

The drainage water managed in agroforestry systems is significantly reduced to 6 — 11 percent of the initial volume. This facilitates final treatment of drainage water in a solar evaporator (or other facilities) for salt and selenium removal.

The relative areas in agroforestry systems are as follows:

Area of (%):	(A)	(B)
• salt sensitive crops	100.00	100.00
• salt tolerant crops	20.07	14.47
• salt tolerant trees	2.00	1.37
• halophytes	.67	.52
• solar evaporator	.26	.26

(A) the example presented in this report

(B) the result of the salt/water balance model calculated at UCD — LAWR (Karajeh, Tanji)

Figure 4 indicates the flow of drainage water through the agroforestry system (Karajeh).

To maintain soil quality, a leaching fraction (the percentage of the infiltrated irrigation water that percolates below the root zone) must be sufficiently high to prevent a build-up of salts, selenium, and boron in the soil profile. The preliminary results of the experimental work indicated the need for applying increased volumes of water to provide for tree/plant ET requirements and for salt leaching. A adequately large discharge outlet for leached salt, a 3-acre solar evaporator, will be added to the experimental project at the Mendota site. This design change, in combination with increased irrigation and improved water application timing, should sustain the long-term quality of soils and provide for a proper testing of a soil/water/salt balance model.

Beside their role in water reuse, the salt tolerant trees and plants have been also used to control shallow groundwater tables and to intercept surface or subsurface flow of water from up-slope areas. Trees have been planted for the above reasons on farms in Madera, Fresno, Kings, Tulare, and Kern counties. These trees must be well established before data from these projects can be evaluated. Additional experimental work is needed to collect data on the effect of trees on shallow ground water.

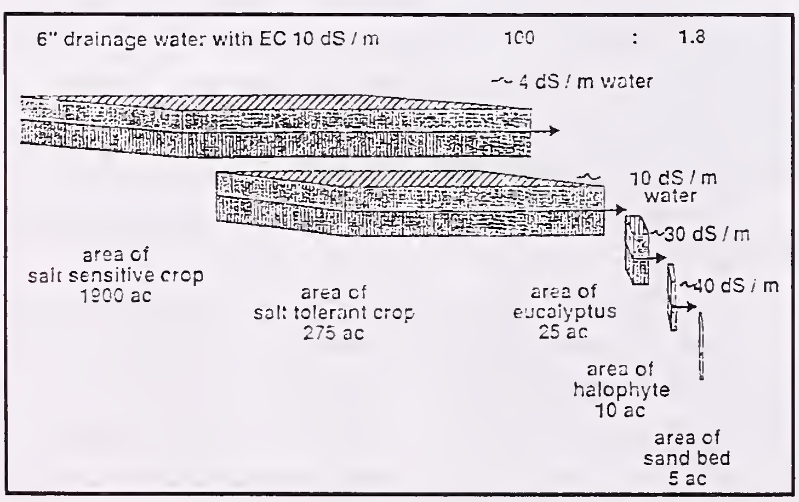

Figure 4 — The flow of drainage water through the agroforestry system (Karajeh).

Wildlife Safety

The west side of the San Joaquin Valley is basically a treeless area. It was apparent from the beginning of the agroforestry program (1985/86) that planted trees attract wildlife. An agroforestry system has been developed primarily for mining salt from irrigated farmland; but it should enhance wildlife habitats in the valley.

The effect of selenium, accumulated by plants and trees, on wildlife safety has been studied. The first study was done by the Department of Biological Sciences, California State University, Fresno; and the second study (still in the review process) by the Department of Fish & Game. The first study was primarily focused on a quantitative evaluation of the wildlife population in agroforestry systems. The second study has attempted to analyze selenium accumulation in wildlife. Both studies have the common characteristics of not separating the effect of evaporation ponds (or surrounding cultivated fields) and agroforestry sites on wildlife. Neither study offers sufficient data to evaluate the safety of trees and salt tolerant plants for wildlife.

A new study needs to be designed to specifically evaluate the effect of agroforestry systems on the quality of wildlife habitats. This study should evaluate the interaction of wildlife with agroforestry systems from a broader perspective; and the following facts need to be taken into consideration:

- Individual patches of salt tolerant trees and plants have existed for many years in the selenium contaminated areas of the valley, and no negative effect on wildlife has been reported. The study done by the University of California, Davis, on selenium accumulation in biomass, indicated that the athel trees grown in a small area about 3.2 km (2 miles) from the Mendota site had a selenium a ccumulation approximately three times higher than that of eucalyptus trees at the experimental (Mendota) site. Athel trees are more attractive to wildlife than eucalyptus trees, but no negative effect of selenium has ever been reported.
- Vegetation on non-cultivated land also

uptakes selenium, and no negative effects on wildlife have been reported (the Kesterson Reservoir area being an exception).

- The agroforestry method applied to irrigated farmland results in the concentration of salt and selenium (when present in soil and water). Experimental data indicate that the selenium concentration may reach the levels of .3 mg/L in drainage water applied to trees and the concentration may increase to .6 mg/L in the drainage water discharged into a solar evaporator. The analyzed levels of selenium uptaken by highly salt tolerant crops (halophytes) are about 1.3 mg/Kg. Analytical data and observations indicate that the small amount of selenium uptaken by trees should not impact the safety of wildlife. Some highly salt tolerant crops may be selenium accumulators. However, the plants can also be selected with the consideration of wildlife safety as related to the efficiency of their selenium accumulation. The plants presently tested in the field do not seem to be efficient selenium accumulators. It is note worthy that salt tolerant crops may remove only a small portion of selenium from the soil/water environment.
- The solar evaporator has been designed with respect to wildlife safety. Any water body attracts wildlife. Therefore, drainage water is not ponded in the solar evaporator. The volume of drainage water, disposed of into a solar evaporator, is correlated with daily water evaporation rates by adjusting the quantity of drainage water pumped and/or the time period of pumping. The shallow layer of water and salt crust does not seem to offer an environment attractive to wildlife. The operation of a solar evaporator may initially require close management; but, it can be developed as an automated process in which the volume of water discharged would be correlated with CIMIS (California Irrigation Management Information System) climatological data.

Economics of Agroforestry Systems

Agroforestry systems offer a complex method for salt mining from irrigated farmland. The economics of agroforestry is a function of many variables. The following values must be weighed against any associated added costs:

- being able to continue the production of high value food crops
- using drainage water as a resource rather than discharging it as waste
- conserving water by reusing drainage water in the area of a given farm to produce marketable crops
- tree biomass harvested for energy and/or industrial feedstock market
- highly salt tolerant plants (halophytes) marketed as livestock forage and/or as indus trial or energy or biomass
- harvesting, handling and transportation costs for tree and halophyte biomass
- mined salt
- selenium transfered with forage or salt for livestock/wildlife feeding in selenium deficient areas
- created wildlife habitats in otherwise "tree less" areas
- cost of drainage water disposal under increasing environmental constraints

An economic analysis including the all areas above would be very beneficial.

Future Plans

While agroforestry systems have been introduced on several farms in California's San Joaquin Valley, the major experimental work is concentrated at three farms sites: the Mendota site, Red Rock Ranch (near Five Points), and the Tulare Lake Drainage District (TLDD). All three projects will be funded by the Bureau of Reclamation for three years. Two of these projects (Mendota and TLDD) are experimental, and a demonstration project will be developed at Red Rock Ranch. All three projects will continue to operate beyond the three-year period as a practical farming method for salt mining.

General agroforestry development plans include:

- continued selection of trees and halophytes
- diversification of planted trees and halophytes
- developing markets for mined salt
- evaluation of the economy of selenium removal methods
- monitoring the use of water by trees
- developing an electronic network for data transfer
- providing information for technology transfer
- developing a salt management model
- developing a selenium management model
- completing the evaluation of agroforestry in relation to wildlife habitat enhancement
- evaluating the economics of agroforestry systems

Specific plans for the Mendota and Red Rock Ranch projects have also been made.

The completion of the experimental project at the Mendota site will require:

- Changes in the relative areas of trees, halophytes and solar evaporator; the tree area will be reduced to 6.6 ha (16.4 acres), the halophyte area will be increased to 2.7 ha (6.7 acres), and the area of the solar evaporator will be increased to 1.4 ha (3.4 acres). This change will improve the efficiency of salt mining, and it will create a sufficiently large area for the crystallization of salt.
- Planting iodine bush *(Allenrolfea occidentalis)* and quail bush *(Atriplex lentiformis)* as highly salt tolerant plants to be irrigated with water drained from the tree area.
- Leveling the area of a solar evaporator, and covering it with a plastic liner.
- Installation of a new system for the collection of drainage water from the tree area.
- Improvement in water distribution systems for the irrigation of trees and halophytes.
- Installation of a system for the even distribution of water in a solar evaporator.
- Installation of automatic controls for water pumping to irrigate the trees, halophytes, and to discharge drainage water into a solar evaporator.
- Maintenance of observation wells, and the installation of new observation wells.

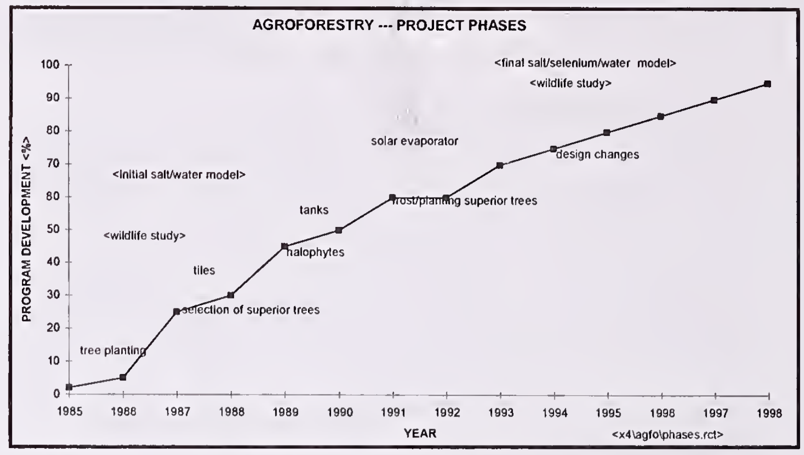

Figure 5 — Experimental work started as a new promising concept and its phases.

The development of the demonstration project at Red Rock Ranch will require the installation of:

- A drainage system for salt sensitive and salt tolerant crops, and for the agroforestry site.
- Salt tolerant trees (eucalyptus, casuarina, and athel) and highly salt tolerant plants (iodine bush and quail bush).
- A solar evaporator.
- Water delivery and monitoring systems.
- A system for even distribution of water in the solar evaporator.
- Automatic controls for water pumping to irrigate trees, halophytes, and to discharge drainage water into the solar evaporator.
- Monitoring wells.

Conclusion

This report provides an overview of work done since 1985/86 in the development of an agroforestry farming method for the management of salt and selenium in the San Joaquin Valley. The project started from the realization that practical bio-engineering methods should be applied to sustain agriculture and wildlife habitats on irrigated farmland.

The experimental work started as a new promising concept; its phases are indicated in Figure 5.

As the project has been progressing, it has been realized that the quality of trees and halophytes must be improved, reused water needs to

be drained from the tree and halophyte areas, and an outlet for salt discharge is required. The interaction of wildlife (its safety) with agroforestry sites has been investigated. A model for salt/water balance goes through development stages. Individual components of the agroforestry concept have been studied. The funding by the Bureau of Reclamation has provided the feasibility to test agroforestry as a system, to collect additional data and to finalize an agroforestry salt/soil/water model. It is estimated that this work will be completed in 1997/98. The project results will be made available to growers, water districts and Resource Conservation Districts for implementation.

The preliminary project results indicate that salt and selenium can be removed from a reduced volume of concentrated drainage water after this water is reused 2 to 3 times in a cropping system; this system is designed upon the principle of differentiated (and sequentially increasing) salt tolerance. Salt tolerant trees and plants need to be properly managed with consideration of soil characteristics, volume and quality of water reused, level of water tables, and climatological conditions. The discharge of the final volume of drainage water into a solar evaporator must be controlled with respect to seasonal evaporation rates. The solar evaporator, with a thin layer of drainage water renewed daily, does not create conditions attractive to wildlife. This is important when selenium is present in soil and drainage water.

Continuing work on the Agroforestry for Sustainable Agriculture project will focus on refining the salt and water balance model, developing a selenium management model, and studying the interaction of other elements (boron). A great challenge is to establish a utility value for mined salt and selenium. The potential impact of selenium concentration on wildlife safety requires an additional study. The selection of salt tolerant trees and plants will continue.

Agroforestry as a farming method for salt and selenium management on irrigated land provides the opportunity to sustain high crop yields on land affected by salinity buildup. It is a complex system which requires appropriate design and operation. It is expected that agroforestry systems will contribute to the sustainability of the ecology of farming and wildlife on irrigated land in California and other world regions.

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Present Status and Future Potential for Agroforestry in the Northern Great Plains[1]

Peter R. Schaefer and John J. Ball[2]

Abstract — The potential for the use of trees and shrubs in sustaining agricultural systems in the northern Great Plains remains largely untapped. Only three percent of the region's cropland and 40% of the farmsteads are protected by agroforestry plantings. Complete protection of cropland, farmstead/feedlots and 10% of the road system in the region requires the planting of 1.2 billion trees and shrubs in addition to the 400 million that are in existing plantings. An emphasis on the establishment of riparian buffers would substantially add to these numbers. The realization of such a massive planting effort is unlikely. Resource managers in the region need to collectively determine attainable goals for the combination of agroforestry and other conservation practices that will best protect the region's natural resources. Such goals should include a much more intensive and integrative use of trees and shrubs in agricultural landscapes. Agroforestry plantings will serve largely for resource protection, as the potential for highly integrated alleycropping or silvopastoral systems is limited by harsh climate and limited markets for species that can be grown successfully.

Introduction

The Northern Great Plains consisting of Montana, Wyoming, North Dakota, South Dakota and Nebraska, comprise an area of nearly 300 million acres. Approximately 33 million acres of the region (11%) consists of mountainous terrain with coniferous forests. This paper will focus on the plains area of the region, and is based on available literature, the authors' experience, and a survey of State and Federal agency personnel (Survey 1994). The survey was sent to 31 individuals representing State Forestry, Tourism, Parks, Game and Fish, Agriculture and USDA Soil Conservation Service offices in each state in the region. Responses were received from 23 offices. The data presented in the following pages represent our best estimates and those of the resource managers in the region.

Trees have been planted on agricultural lands in the Northern Plains for well over 100 years. The Prairie States Forestry Project planted over 100 million trees and shrubs in the five states during the years 1935-1942 (CWSF 1993). Plantings from the 1940's to the present have averaged in excess of 10 million seedlings/yr (GPAC Forestry Committee Annual Reports), ranging from 500,000/year in Wyoming to 5,000,000/year in North Dakota. North Dakota has led the nation since 1940 in planting trees for windbreaks. Agroforestry plantings in the region are comprised almost entirely of protective plantings (Figure 1).

Native woodlands have never been abundant in the prairie region of the Northern Plains, with North Dakota having the fewest woodland resources of any of the 50 states. Conversion to agricultural purposes and water development projects continue to impact these lands (Bratton *et al.* 1993), while tree planting activities have been

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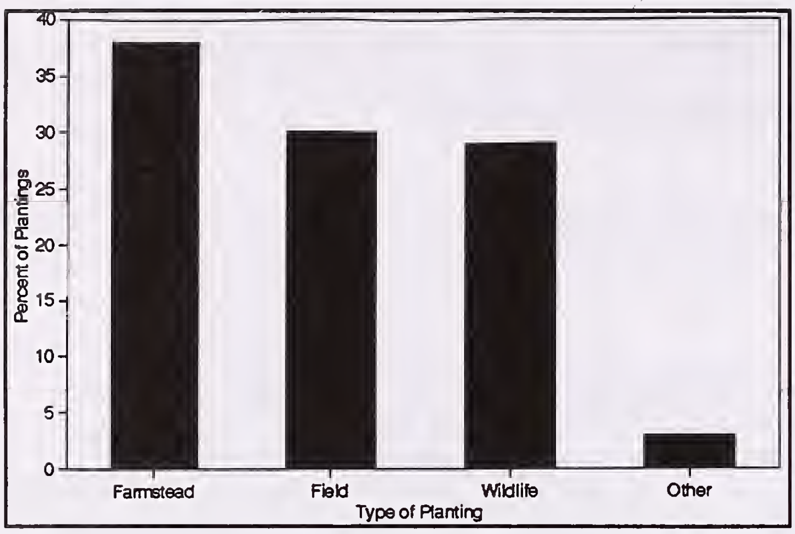

Figure 1 — Occurrence of agroforestry plantings in the Northern Great Plains.

minimal to non-existent. Most major forest regions adjacent to the prairie (i.e., Black Hills, SD; ponderosa pine forests of northwestern NE, and conifer forests of WY and MT) have been under federal management for nearly a century, with concomitant regulation of agricultural and extractive activities.

Climate and Soils

The climate in the Northern Plains is characterized by low and variable precipitation, low humidity, large differences between summer and winter temperatures and large changes in temperature in any season, persistent winds, high relative evaporation, recurring drought and violent storms. Precipitation ranges from about 10" in the northwest to 32" in the southeast, with seventy-five percent falling during the growing season. Relative evaporation ranges from 32" to 48" in most of the region, with Nebraska at 48"- 64". Winds average 10 to 15 mph.(Ottoson et al. 1966, Geological Survey 1970). Summer temperatures are generally 60°F - 70°F higher than winter temperatures. The region experiences 10 - 30+ days above 90°F, with 120-180+ days below 32°F. The frost free period ranges from 120-180 days (Geological Survey 1970).

The soils of the region are broadly mollisols, entisols and aridisols. Aridisols cover much of Wyoming, and entisols much of the Sandhills of Nebraska, the badlands of South Dakota and

Table 1 — Land capability classes in the Northern Plains.

Class	MT	WY	ND	SD	NE	Region
	Percent in Class					
I	0	0	0	4.1	5.5	1.7
II	0.5	1.0	51.4	28.3	19.4	17.7
III	24.0	9.2	20.0	18.7	15.3	18.8
IV	13.5	18.0	7.5	14.7	13.4	13.2
V	0.5	0.6	1.5	0.8	1.3	0.9
VI	35.5	37.9	10.6	23.3	32.5	28.7
VII	24.0	29.1	8.3	8.3	9.2	16.3
VIII	2.0	4.1	0.7	1.8	0.3	1.7

North Dakota, and eastern and central Montana (Geological Survey 1970, Aandahl 1982). Most agroforestry plantings in the Northern Plains are concentrated on the better soils for tree growth (ie., windbreak suitability group III or better). In South Dakota 80% are on class III or better soils, and 94% are on class V or better (Schaefer *et al.* 1987).

Land Capability and Use

The potential native vegetation of the region ranges from bluestem prairie to wheatgrass-bluestem-needlegrass, wheatgrass-needlegrass, and grama-needlegrass-wheatgrass from east to west. Nebraska Sandhills prairie and grama-buffalograss would be typical of western Nebraska, while large areas of sagebrush steppe and wheatgrass-needlegrass shrubsteppe are typical of central and southwestern Wyoming. Woody vegetation consists of oak-hickory forest in eastern Nebraska and northern floodplain forest along the major rivers of the region. Significant areas of ponderosa pine occur in South Dakota, Nebraska and North Dakota, and conifer forests are widespread throughout the mountainous regions of Wyoming and Montana (Geological Survey 1970).

Two-thirds of the Dakotas and Nebraska are suited to cultivated crops compared to one-third for Wyoming and Montana (Table 1) (Survey 1994). Cropland in Montana and Wyoming is generally class III or IV, with severe limitations for cultivated crops (Klingebiel and Montgomery 1961).

About 18% of the region is unsuited to the effective use of trees and shrubs (classes VII and VIII, Table 1). Soil features and climate also restrict the potential for successful tree and shrub plantings on class VI lands. Land use in the region reflects land capabilities as previously described (Table 2).

Justification for Agroforestry

Survey participants were asked to indicate the extent to which several agricultural practices were found in their state. The occurrence of clean cultivation, streamside grazing, cropping to field borders, herbicide/pesticide and fertilizer use, and cropping of highly erodible lands is moderate to extensive in the region. Grazing native woodlands and cropping of field units greater than 160 acres occurs at moderate levels. There is a limited to moderate use of livestock confinement operations and center-pivot irrigation. There was general agreement among respondents that all of the practices listed except center-pivot irrigation were causing significant damage to the region's natural resources (Table 3). Greater incorporation of trees and shrubs is one means to mitigate the problems presented by several of these practices.

Table 2 — Major land use in the Northern Plains.

Land use	MT	WY	ND	SD	NE	Region
	Percent in Use					
Crop	19.0	4.6	62.2	38.4	41.7	29.3
Pasture	3.0	1.0	2.7	5.1	4.0	3.0
Range	52.0	75.2	21.9	47.8	46.3	50.7
Forest	24.0	15.6	0.9	4.0	1.5	11.8
Other	2.0	3.6	12.3	5.5	6.6	5.2

Soil Erosion and Costs to Society

Well over half of the crop/rangelands in the region have total erosion in the 5 - 13.9 t/ac/yr range (Figure 2) (USDA-SCS 1985). Wind erosion

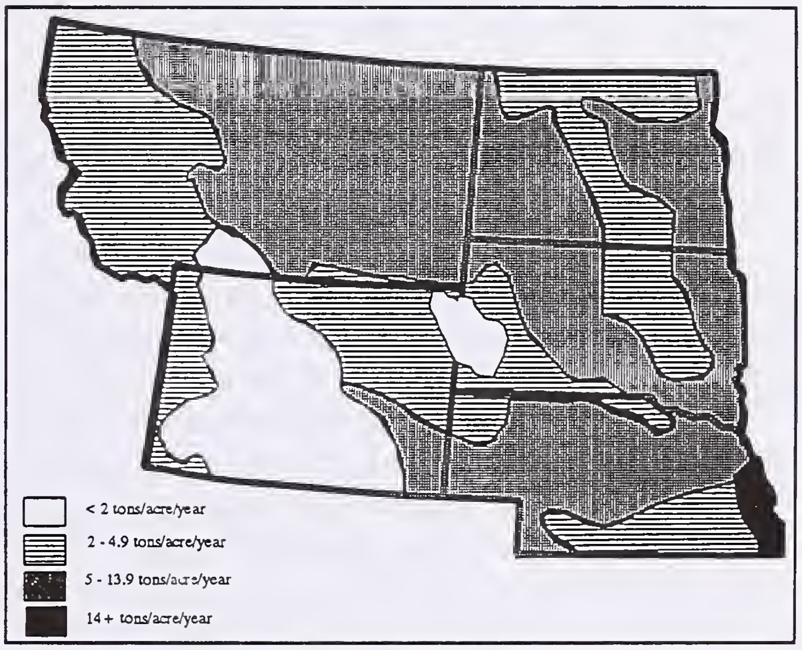

Figure 2 — Average annual erosion on cropland in the Northern Great Plains.

Table 3 — The degree to which selected agricultural practices cause significant damage to soil, water, and other natural resources in the Northern Great Plains[1].

Practice	SCS	FOR	G&F	AG	"Average"
			Percent in Use		
Clean cultivation	A[2]	A/SA	SA	N/A	A
Grazing native woodlands	A	SA	SA	A	A/SA
Grazing next to streams	SA	SA	SA	N/A	SA
Cropping to field borders	A	A/SA	SA	A/SA	A/SA
Use of herbicides and pesticides	N	A	SA	N	A
Use of fertilizers	N	A	A/SA	N	N/A
Cropping field units greater than 160 ac.	N	A	A	A	A
Livestock confinement	N	A	A	N/A	A
Center pivot irrigation	N	N	A	D/N	N
Cropping highly erodible lands	A	A/SA	A/SA	SA	A/SA

[1]*Ratings were based on responses from five State SCS, four State Forestry, four State Game & Fish, and two State Agriculture offices.*

[2]*SD - strongly disagree, D - disagree, N - neutral, A - agree, SA - strongly agree.*

accounts for 60% - 70% of gross erosion on cropland in the Northern Plains. In excess of 30% of this cropland is eroding above T (Alt *et al.* 1989, Survey 1994), and 26% is highly erodible (*i.e.*, Erodibility Index (EI) > 8, 1987 NRI). Reducing soil loss is probably the most commonly accepted reason for planting trees in the region.

Projected crop yield losses over the next 100 years due to erosion are 1.4% for the Northern Plains and 3% for the nation (Alt *et al.* 1989). The offsite costs of soil erosion are likely much more significant to society than losses in crop yield, and may approach $15 billion per year (Crowder *et al.* 1988, Alt *et al.* 1989). These include damage to water quality, navigation, lakes and reservoirs, flora and fauna, and recreation values.

Water Quality

Water quality in the Northern Plains is primarily impacted by agriculture. The potential pollutants include sediment, pesticides, nutrients, bacteria and dissolved solids (Crowder *et al.* 1988). Cropland is responsible for over one-third of the sediment that reaches the Nation's waters each year, and pasture and rangelands account for about a quarter of the total (Welsh 1991). Damage from dissolved nutrients, pesticides, salts and bacteria to surface water ecosystems has not been quantified (Crowder *et al.*, 1988). Good data for pesticide/nitrate levels in ground water in the region does not exist.

There are also concerns regarding ground water quality and quantity (Survey 1994). Nutrients and other agricultural chemicals in well-water, and depletion of ground water reserves are chief among these.

Regional Sustainability

The region's economy is based heavily on agriculture, and will continue to be in the future. Survey respondents suggest that agriculture has the greatest promise for improving the future economic outlook of the region. However, they also agreed that agriculture must change to maintain and/or increase its role in sustaining viable agricultural ecosystems and local and state economies. Important in this change is the need to provide greater protection of the region's natural resources. Recreation/tourism and industrial development were also recognized as important components in improving regional sustainability.

Survey respondents representing State Recreation and Tourism Departments (9 individuals) indicated that trees and shrubs in agricultural landscapes were of high value to recreation and tourism in the region. They also felt that the inclusion of more trees and shrubs in agricultural landscapes would increase a landowner's opportunities for providing fee-based recreation, primarily as a result of increased wildlife and fish populations.

Activities associated with wildlife and fish are very important components of the recreation/tourism economy in the region (Survey 1994). Respondents from Game & Fish Departments strongly agreed that trees and shrubs in the landscape are important in maintaining viable populations of big and small game, upland gamebirds and nongame mammals, songbirds,etc. They agreed that trees and shrubs benefit fish and other aquatic species.

Sustaining rural economies is an issue of considerable import in the Northern Plains as in other agricultural regions. Two important components of the regional economy, agriculture and recreation/tourism, would benefit from a more intensive use of trees and shrubs in agricultural systems.

Status of Agroforestry

The area of protective forestry plantings in the Northern Plains is about 1,000,000 acres (Bratton *et al.* 1993, CWSF 1993, Survey 1994), with about 100,982 miles of field and farmstead windbreaks in 1990 (Bratton *et al.* 1993). Most of these windbreaks were established in the last 60 years. The windbreak resources in Nebraska, South Dakota and North Dakota are considerably larger than those of Montana and Wyoming (Table 4). There are presently about 400,000,000 trees and shrubs in agroforestry plantings in the Northern Plains (extrapolated from Survey data, Bratton *et al.*

1993, and CWSF 1993). Current statistics for the major agroforestry plantings are presented in Table 4. Although presently comprising only a small percentage of agroforestry plantings, there are several additional types of plantings with potential significant future impact. Native woodlands are also a significant agroforestry resource.

Living Snowfences

The extent of living snowfence plantings in the region is not well documented. Brandle *et al.* (1992) estimate less than 500 miles in the entire Great Plains. Survey results suggest a range of 500 to 2000 miles, almost entirely in NE. Wyoming, however, has developed many demonstration living snowfences, and the number of miles of living snowfence is increasing.

Riparian Buffers

There are apparently no states in the region with significant areas of artificially established riparian buffer strips of woody vegetation. Riparian restoration is apparently an area of growing interest throughout the region, and several State Forestry agencies in the region are establishing demonstration plantings of such systems.

Timber/Grazing

Grazing on timber lands is a common and important practice in the region, particularly in South Dakota, Wyoming and Montana where significant areas of ponderosa and other pine forests are found. Grazing on these montane forests is generally of low intensity, with much of these lands under federal management. Grazing also occurs in the prairie regions, particularly in riparian areas, but also to a significant degree in windbreaks. Grazing of livestock in these latter situations is unregulated, intensive, and extremely damaging to forest resources on the site. Improper management of riparian areas through excessive grazing and trampling can reduce or eliminate riparian vegetation, cause channel aggradation or degradation, cause a widening of stream channels, change streambank morphology and lower surrounding water tables (Clary and Webster 1989).

Native Woodlands Adjacent to Agricultural Lands

In excess of 1,000,000 acres of riparian/bottomland forests are found in the region (Survey 1994). These woodlands are extremely important to wildlife and provide significant water quality benefits (Chaney *et al.* 1993). A rough estimate of the riparian zone based on survey responses is 250,000 miles. Garrett *et al.* (1994) estimate 155,555 miles of riparian zone in the region, 92% of which lacks woody vegetation (based on 1982 NRI). Survey respondents suggested that twenty-five percent of the riparian zone is without, <u>and in need of</u>, riparian forest vegetation. Information regarding the actual condition of riparian areas is almost entirely lacking.

Upland hardwood forests are limited to about 500,000 acres in the Northern Plains (Survey

Table 4 — Non-native woodland resources in the Northern Great Plains[1].

State	Field Windbreaks M miles	Field Windbreaks M acres	Farmstead/Feedlot M acres	Wildlife M acres	# Windbreaks (M)
North Dakota	55.4	162.8	123.1	203.4	168.2
South Dakota	9.8	93.0	145.5	36.8	94.1
Nebraska	9.9	85.0	52.0	10.0	117.3
Wyoming	0.4	1.0	6.3	0.1	5.6
Montana	8.8	26.4	25.0	12.0	26.2
Total	84.3	368.2	351.9	262.3	411.4

[1] *The information in this table was based on data in CWSF (1993), Bratton et al. 1993, and survey responses from State SCS and Forestry offices. The most optimistic number from among these sources was used.*

1994), and are generally associated with the larger rivers and rolling hills in the region. Roughly 3 - 5 million acres of montane, coniferous forests are closely associated with agricultural lands (Survey 1994). Agricultural uses of these forests include timber production and grazing. Unlike most of the other native forests in the region, much of this type is under federal management.

There are also approximately 600,000 miles of wooded strips in the region, owned primarily by farmers and ranchers. Fuelwood is probably the dominant use of these strips.

Condition of Woodland Resources

Both native and planted woodlands in the Northern Plains outside of the montane forests are declining in vigor and perhaps in total land area (Schaefer *et al.* 1987, Bratton *et al.* 1993, Survey 1994). Several factors are thought to be responsible for the decline of planted woodlands, including advanced age, diseases, improper management and agricultural practices. The extent to which native woodland resources have declined in recent years is not known precisely, but it appears that these losses have been significant. Powell *et al.* (1993) estimate a 12% decrease in timberland on all ownerships from 1952 to 1987. These losses are primarily the result of clearing for agriculture and flooding of low areas due to dam construction. American elm was a dominant species in the bottomland forests of Nebraska and the Dakotas. Elm volume in native woodlands has dropped 75% over the last four decades due to Dutch elm disease. Losses of native woodlands are anticipated to continue.

Potential for Agroforestry

Cultivated cropland is viewed as the agricultural sector most lacking in sustainability throughout the region, with fallow systems and low residue crops the least sustainable practices, leading to excessive soil and organic matter loss, soil salinity and water quality impacts (Survey 1994). Survey respondents agreed that agricultural systems need to address these problems. They also suggested achieving agricultural sustainability rested on agriculture becoming more efficient while maintaining or improving the region's resource base. They cited more protection of topsoil, especially to limit the loss of organic matter; less reliance on summer fallow; a need to maintain or improve soil fertility; a continued reduction in off-farm inputs, particularly farm chemicals; greater diversification; and continued technological development and application as means to achieving agricultural sustainability in the region.

Several papers in recent years have addressed the potential of woody plants for improving the sustainability of agricultural systems in the Great Plains (Schaefer 1989, Rietveld *et al.* 1990, Schaefer and Rietveld 1991, Brandle *et al.* 1992a). The proper use of trees and shrubs in support of agriculture will: protect the soil so that erosion, contamination of surface waters from sediments, and losses of water and nutrients are reduced and overall soil quality is maintained or improved; provide for the cultivation of a diversity of crop species to improve the biological and economical stability of agriculture; improve farm profitability without sacrificing production; and enhance the quality of life both on the farm and for society as a whole.

Extent to Which Sustainable Practices Should Be Employed

Diversification of farming operations, residue management and crop rotation were the only practices given high potential to improve agricultural sustainability averaged over all respondents (Table 5). Most agroforestry practices and agronomic conservation practices were viewed to have moderate or moderate to high potential. Fuelwood plantations and integrated tree-pasture systems were viewed as having little potential. However, survey participants indicated that many of the benefits derived from incorporating woody plants into agricultural systems were moderately to highly important to achieve and/ or maintain sustainable agricultural systems in

the Northern Plains (Table 6). The participants recognized that difficult growing conditions and limited markets restrict the ability of landowners to generate additional income from wood products.

The Need for Protective Plantings

After over 100 years of planting trees and shrubs in the region, the potential for their use in sustaining agricultural systems remains largely untapped. Not more than three percent of the cropland in the region was protected by windbreaks in 1987 (Brandle *et al.* 1992a), leaving 85.5 million acres unprotected. Providing protection to highly erodible lands would require 600,000 miles of field windbreaks (40 feet tall with protection to 10 heights). Protecting the remainder of the cropland from the environmental rigors of the region would require 555,000 miles of field windbreaks (40 feet tall with protection to 20 heights). It would take nearly 610,000,000 trees planted 10

Table 5 — The potential of several agroforestry and agronomic practices for improving the sustainability of agricultural systems in the Northern Great Plains[1].

Practice	SCS	FOR	Response by Agency G&F	AG	"Average"
Residue management	H[2]	H	L/M	H	H
Field windbreaks	M/H	M/H	H	M	M/H
Living snowfences	L/M	H	H	L/M	M/H
Diversified farming ops.	H	M/H	H	M/H	H
Farmstead/feedlot windbreaks	M	M/H	M	M	M
Riparian buffer strips	M	H	H	M	M/H
Alley cropping	L	H	H	L	M
Wildlife plantings	M	L/M	H	M	M
Native woodlot management	L/M	M	M/H	M	M
Fuelwood plantations	L	L	M/H	L	L
Integrated tree-pasture systems	L	L/M	M/H	M/H	M
Crop rotation	H	H	M/H	H	H
Other agronomic practices	M	M/H	M/H	H	M/H

[1]*Ratings were based on responses from five State SCS, four State Forestry, four State Game & Fish, and two State Agriculture offices.*
[2]*H - high, M - moderate, L - limited.*

Table 6 — The importance of selected benefits of trees and shrubs to achieving and/or maintaining sustainable agricultural systems in the Northern Great Plains[1].

Benefit	SCS	FOR	G&F	Response by Agency P&T	AG	"Average"
Control of soil erosion	M[2]	H	H	H	M	M/H
Crop protection	M/H	H		H	M	M/H
Removal of ag. chemicals from surface and ground water	L/M	H	H	H	L	M
Diversification of ag. ecosystems	M	H	H	H	M/H	M/H
Increased hunting and/or non-consumptive wildlife values	H	H	H	H	M	H
Improved quality of life	H	H		M/H	L	M/H
Income from wood products	L	M		M	N/L	L/M
Increased farm productivity	M	M/H		H	M/H	M/H
Decreased energy use	M	M/H		M/H	M	M

[1]*Ratings were based on responses from five State SCS, four State Forestry, four State Game & Fish, five State Parks and Tourism, and two State Agriculture offices.*
[2]*H - high, M - moderate, L - limited, N - no importance.*

feet apart in single rows to establish such a system of windbreaks. Garrett *et al.* (1994) estimate that 22.7 million acres of pasture/rangeland in the region have medium to high potential for conversion to cropland or agroforestry. The minimum practice of establishing field windbreaks upon conversion of these lands would require in excess of 230,000,000 trees and shrubs (450,000 miles).

The potential for planting new farmstead/feedlot windbreaks, although still substantial, is not as high as that for field windbreaks. Windbreaks presently protect 70,156 of the 165,647 farms in the Northern Plains (Brandle *et al.* 1992a, Womack 1993). Farmstead/feedlot windbreaks in the region average five acres in size. All of the unprotected farms could be protected by 477,455 acres of windbreaks (208,000,000 trees and shrubs).

The Northern Plains contains 351,569 miles of rural roads (Brandle *et al.* 1992a). Protecting 10% of the road system would require 35,000 miles of living snowfence. Establishing three to seven rows/planting requires 69,300,000 to 115,000,000 trees and shrubs for 35,000 miles of living snowfence.

It is not possible to quantify the potential need for other types of protective agroforestry plantings, such as those for riparian buffers and wildlife habitat. Considerable wildlife plantings have been established in the region (27% of agroforestry plantings). We assume that the need for additional wildlife plantings is similar to the needs for other windbreak types already mentioned. The establishment of riparian buffers is in its infancy in the region.

Agroforestry practices such as fuelwood and Christmas tree production have limited opportunity for expansion. Over 12 million cubic feet of fuelwood is harvested from outside of the National Forests. Expansion is limited in many areas because the annual harvest exceeds growth. Christmas tree production, primarily as choose-and-cut operations, has the potential to expand to three to four times current production. This is very optomistic, since the best opportunity for choose-and-cut is within 25 miles of a major market (population of over 5000).

Advancing Agroforestry

Survey participants were asked to indicate what the focus should be in advancing the increased use of trees and shrubs in agricultural landscapes. Their responses suggested that a high priority should be placed on establishing field windbreaks, focusing on their economic benefits. A high priority should also be placed on promoting the energy conservation benefits of farmstead/feedlot windbreaks. Wildlife habitat and snow management were additional areas of importance. In no instances did respondents suggest promoting other than traditional conservation uses for agroforestry plantings. In addition to the focus on specific practices, respondents recognized the need for more aggressive and knowledgeable resource managers and technical advisors, thoughts echoed by Garrett *et al.*, (1994).

Landowners and producer groups were recognized as the most important target audiences for the agroforestry message (Survey 1994). Only one respondent mentioned Congress, and only one mentioned school-age children. A recent survey of landowners who planted trees in North Dakota underscored the importance of landowner initiative, contact with other landowners and conservation districts in the decision to plant trees (NDSU 1994).

Present promotion of the use of trees and shrubs in agricultural landscapes is primarily directed at farmstead/feedlot and field windbreaks, and wildlife habitat plantings (Survey 1994). In addition, state forestry personnel typically promote the management of native woodlands, and state game and fish departments are particularly interested in wildlife plantings, generally providing cost-share incentives for these.

Obstacles or Constraints to Agroforestry

Several real and imagined obstacles limit the potential for agroforestry in the Northern Plains. Drought, poor soils and the care required to establish successful plantings are very real obstacles over much of the region. The high cost and

difficulty of windbreak renovation is also an obstacle. The use of herbicides restricts the use of trees and shrubs throughout the extensive small-grain region of the region, as does the lack of reliable markets for wood products. Inflexibility in the federal Farm Program and the short-term management horizons that characterize many agricultural operations provide additional constraints to agroforestry.

Misperception about windbreaks and other conservation practices is also an obstacle to agroforestry. Many farmers persist in the belief that windbreaks cost their operation rather than provide an economic benefit. In addition, the belief that residue management is sufficient to control erosion discourages the acceptance of trees and shrubs. Finally, the promotion of agroforestry practices is highly erratic among, and even within, agencies responsible for agroforestry resources in the region. The problem may go beyond erratic promotion to actually discouraging the use of trees and shrubs in some instances (Survey 1994).

Opportunities for Agroforestry

Greater sensitivity to environmental concerns by rural landowners and society at large may lead to increased acceptance of trees and shrubs in agricultural landscapes. Conservation Districts and/or private entrepreneurs can take advantage of this by providing complete tree establishment and care services. The most common suggestion of survey respondents was that improved or otherwise increased cost-share programs, and stronger educational efforts at all levels would provide the greatest opportunities for agroforestry. Included in the educational emphasis was the increased focus on demonstration projects. Ninety-eight percent of the respondents in a survey of North Dakota and Montana landowners indicated a need for more windbreak education (Laughlin and Tuskan 1988). Respondents also suggested that changing the farm program to not penalize agricultural producers for planting trees on base acres, and inclusion of soil loss and water quality issues in the 1995 farm bill would stimulate a greater interest in agroforestry in the region.

The Need for Agroforestry

In light of the large acreages potentially available for agroforestry plantings, and assuming that obstacles can be overcome and opportunities taken advantage of, do resource managers see a need for more trees and shrubs in the region? Survey participants indicated a moderate to high need for most conservation practices, with riparian areas most critically in need of restoration (Table 7). The need for fuelwood plantations and "traditional" agroforestry practices (alley cropping, tree-pasture) was not rated highly. Survey

Table 7 — The extent to which several agronomic and agroforestry practices are needed in the Northern Plains[1].

	Response by Agency				
Practice	SCS	FOR	G&F	AG	"Average"
Residue management	H[2]	H	L/M	M/H	M/H
Field windbreaks	M	H	H	M/H	M/H
Living snowfences	M	M/H	H	M	M/H
Diversified farming ops.	M	H	M/H	M	M/H
Farmstead/feedlot windbreaks	M/H	H	M	M	M/H
Riparian buffer strips	H	H	H	M	H
Alley cropping	L	M	M/H	L/M	M
Wildlife plantings	H	M/H	H	L/M	M/H
Native woodlot management	M	H	H	M	M/H
Fuelwood plantations	L	L	M/H	L/M	L/M
Integrated tree-pasture systems	L	M	M/H	M	M
Crop rotation	H	M/H	M	M/H	M/H
Other agronomic practices	M/H	M	H	M/H	M/H

[1]*Ratings were based on responses from five state SCS, four state Forestry, four state Game & Fish, and two State Agriculture offices.*

[2]*H - high, M - moderate, L - limited.*

respondents indicated that the presence of trees and shrubs in agricultural landscapes in the Northern Plains is below that needed.

There is a major need to plant trees and shrubs to renovate or replace deteriorating windbreaks. The North Dakota Forest Service and 1992 NRI data indicate as much as 70% of the windbreaks in that state will need renovation by the year 2000. In excess of 60% of the windbreaks in South Dakota have been estimated to need renovation (Schaefer *et. al* 1987). The SCS in North Dakota responded that living snowfence and riparian plantings are most needed, requiring increases of 5000% and 1000%, respectively. Tree and shrub planting needs in North Dakota also extend to field windbreaks (300% increase), wildlife plantings (400% increase) and woodland plantings (100% increase). Responses from the South Dakota Division of Forestry suggest a doubling to quadrupling of field and farmstead windbreaks, especially in drier areas of the state. They also suggested that much more effort be directed toward riparian buffers. Substantial increases in the number of field and farmstead windbreaks in Nebraska are needed as well. This need is projected by the SCS at 10,000 miles of field windbreaks in dry cropland areas, and 6,000 farmstead/feedlot windbreaks. Again, the need to focus more attention on riparian areas was noted. The need in Montana and Wyoming is primarily for more field windbreaks on non-irrigated cropland with highly erodible soils. Although numerical estimates were not given, the need in both states was perceived to be "very large."

Indeed, the need for additional agroforestry plantings in the Northern Plains is "very large." The difficulty lies in defining what "very large" means. The needs expressed for the Dakotas and Nebraska, while indicating a significant increase over present agroforestry efforts, fall short of the "potential" outlined earlier and also discussed by Brandle *et al.* (1992a). It will be important for resource managers and agencies to reach common goals regarding the extent to which various agroforestry practices are needed, as a first step toward achieving significant gains in agroforestry in the region.

Conclusions

Clearly trees and shrubs could be vastly more prominent features of agricultural landscapes in the Northern Plains. However, it is unlikely that Agroforestry in the Northern Great Plains will include extensive use of such practices as alleycropping, silvopasture or forest farming. The difficult environment and soils throughout much of the region often preclude the production of acceptable "crop" trees in such systems. Success with these systems will likely be limited to the more humid eastern border of the region, particularly in eastern Nebraska.

Windbreaks and other buffer plantings will remain the major use of trees and shrubs on agricultural lands. However, the use of windbreaks and buffers must be much more intensive and integrative on agricultural lands to realize their potential for sustaining agricultural systems.

The extent to which agroforestry practices are accepted by landowners is dependent on many factors. Perhaps most important are the rapid changes occurring in agricultural operations and landscapes. These changes have been dramatic both demographically and operationally since the first extensive windbreak plantings of the 1930's and 40's. Consideration of the agricultural community that windbreak systems were originally designed for must be contrasted with present agricultural systems and especially those projected for the future. The potential for agroforestry practices to have a significant impact on future agricultural landscapes is contingent upon the structure of the future agricultural community. The bottom line is that efforts to incorporate agroforestry into sustainable agricultural systems must not lose sight of the larger forces influencing agriculture.

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Agroforestry and Sustainable Systems in the Southern Great Plains[1]

Steven Anderson[2]

Introduction

The southern Great Plains generally includes those areas of the Great Plains in the states of Kansas, Oklahoma and Texas that are west of the 35-inch precipitation isohyetal. This generally follows the area identified under the Great Plains Conservation Program (Figure 1) including the high plains, central rolling and plains and prairies, desert plains, Edwards plateau, Rio Grande plain and Crosstimbers land resource regions (Austin, 1972).

The National Agroforestry Center suggests agroforestry is the "appropriate use of trees and shrubs in support of agricultural production, resource conservation, and human environments". In this context, agroforestry may include traditional agro-silvo-pastoral combinations but also windbreaks for fields, livestock and homesteads; fuelwood plantations; living snow fences; riparian management and buffer strips; wildlife habitat; and home gardens. It is in this broad definition in which the spirit of this paper is presented.

Regional Description

Climate

The regional distinctiveness of the Great Plains climate lies basically in its precipitation. Because the Rocky Mountain rainshadow prevents importation of moisture from the Pacific Ocean, the Gulf of Mexico is the origin of much of the region's precipitation (Robb, 1959). The southern Great Plains is characterized by a sharp decrease in rainfall westward from the 100th meridian (Borchert, 1950) where annual rainfall decreases gradually from 35 to 40 inches in the forest-grassland tension zone on the east to less than 20 inch-

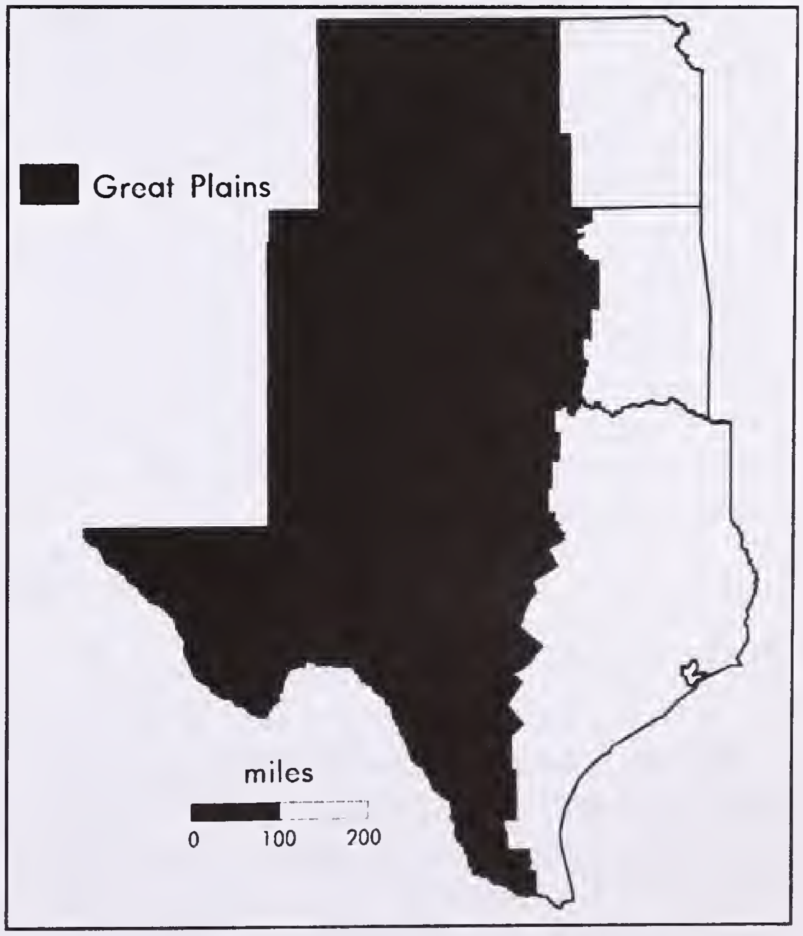

Figure 1 — Generalization of the southern Great Plains (adapted from: Soil Conservation Service, 1981).

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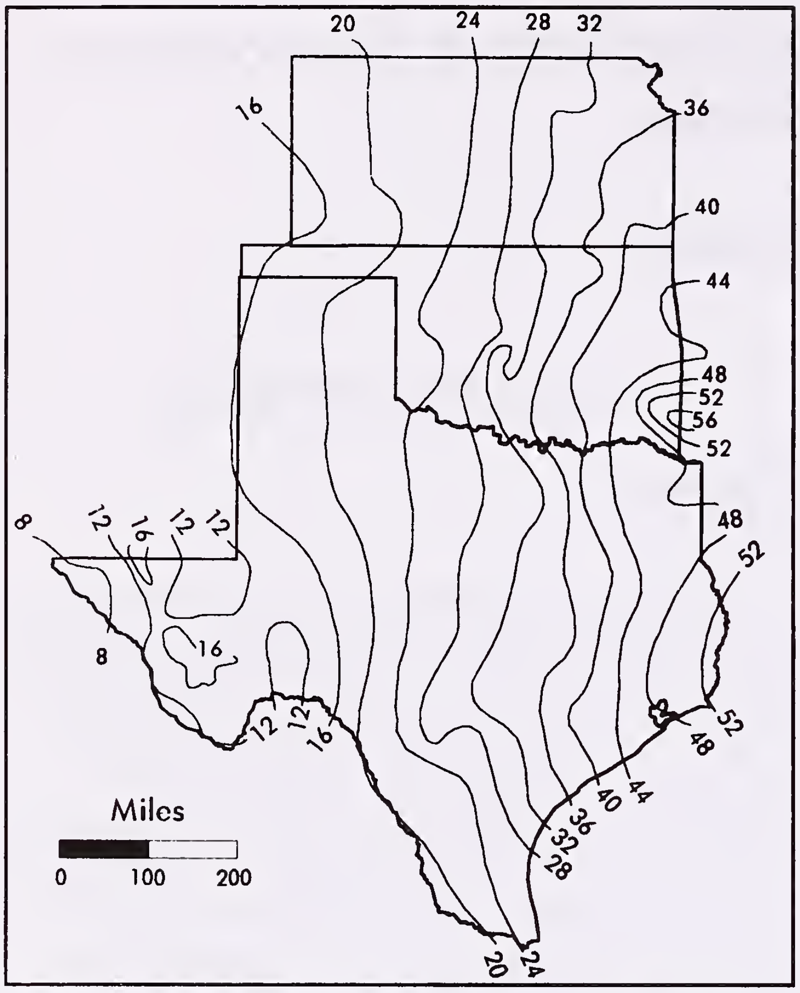

Figure 2 — Normal annual total precipitation - inches (US Department of Commerce, 1983).

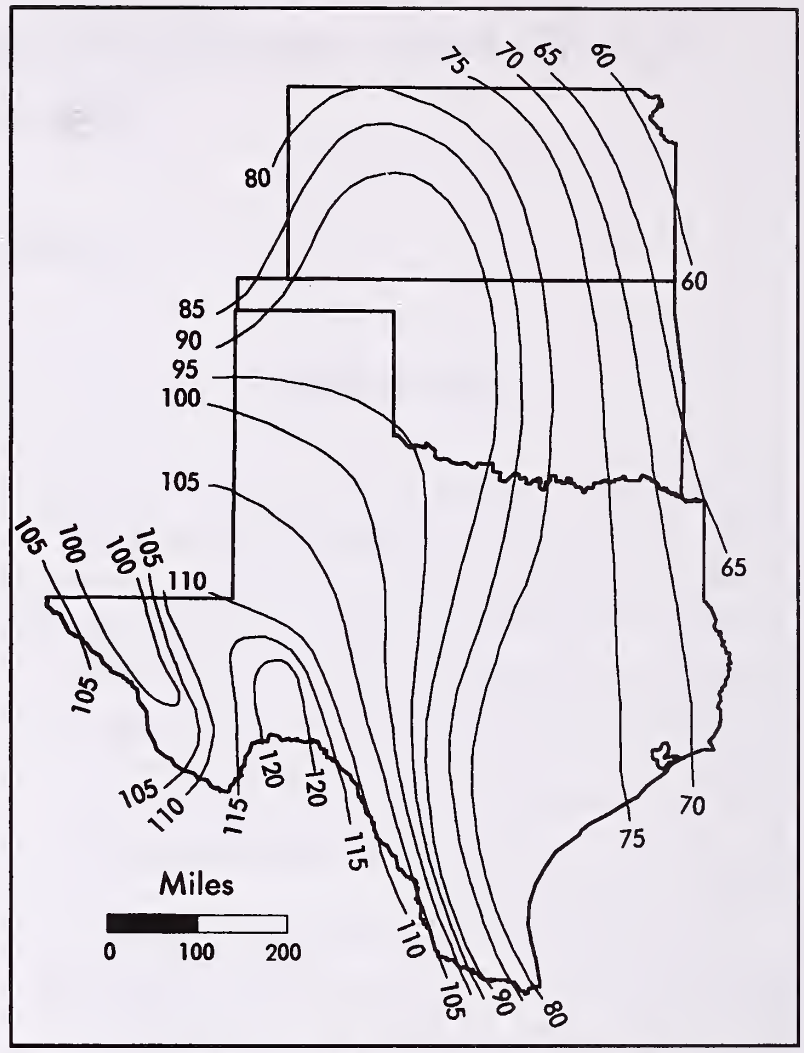

Figure 3 — Mean annual class A pan evaporation - inches (US Department of Commerce, 1983).

es in the short grass-desert shrub ecotone on the west (Harper, 1940). While 75 percent of the total precipitation in the region occurs during the growing season, the distribution of rainfall causes severe moisture stress during many years (Richardson and Burnett, 1983). The combination of hot winds and high temperatures produces rapid evaporation, often injuring crops (Curry,1970) and modifying patterns of natural vegetation (Harrington and Harman, 1991). Potential evaporation in the region greatly exceeds rainfall (Figures 2,3).

Soils

The predominant soils of the southern Great Plains are mollisols and alfisols (Figure 4) while some entisols, vertisols, inceptisols and aridosols also occur. Soils and their constraints are important considerations in evaluating agroforestry alternatives. Agroforestry systems can play

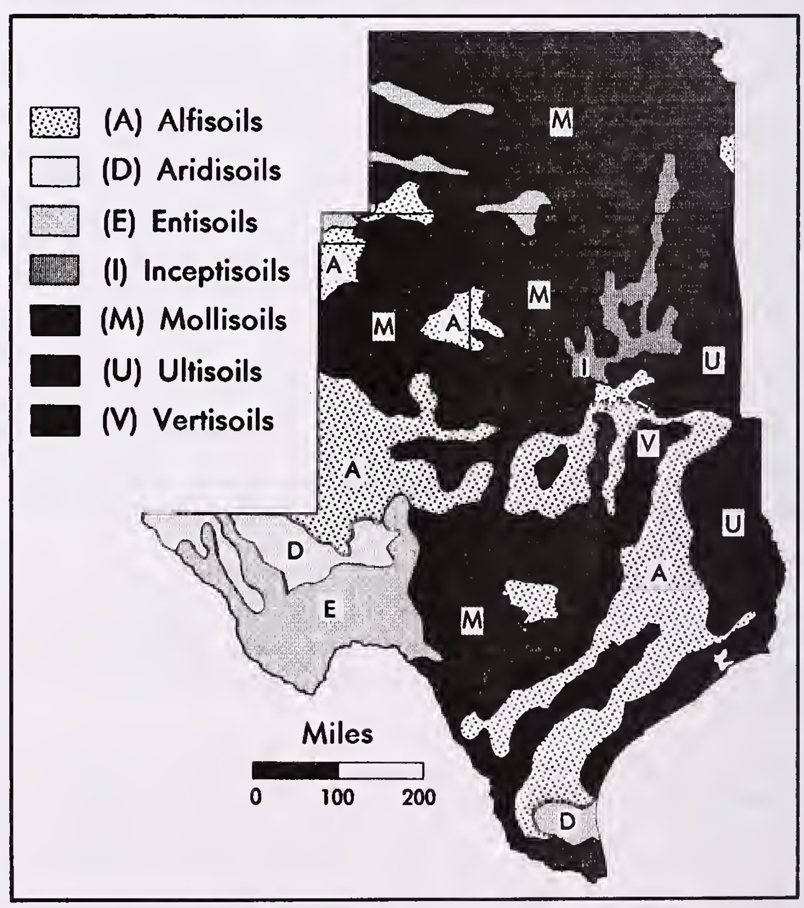

Figure 4 — Soil orders in the southern Great Plains (adapted from: Soil Conservation Service, 1967).

meaningful roles in reducing nutrient losses, regulating soil temperature and moisture, and managing the soil organic matter pathways. The predominant mollisols and alfisols of the southern Great Plains have high agroforestry potential. They are generally fertile; provide for good root development; have a potential for nutrient pumping from deeper, base-rich soil layers; and have moderate to high nitrogen fixing potential (Szott et al., 1991). The fertile alluvial entisols (fluvents) may also have agroforestry potential. Limitations in the southern Great Plains include erosion risks and moisture and temperature limitations.

Land-Uses

The total surface area of Kansas, Oklahoma and Texas is about 268 million acres with approximately two-thirds being located in the Great Plains region. About 92% of the land is undeveloped non-federal rural land (Table 1) utilized for cropland (29%), pastureland (11%), rangeland (51%) and forestland (7%).

The Place For Agroforestry

Few agriculture-related environmental problems do not have at least some relationship to trees and hence, agroforestry. Concerns about water quality, both surface water and groundwater, have become paramount issues. Erosion by both wind and water not only contribute to water quality dilemmas but can have significant and cumulative impacts on site productivity. It is now understood that riparian zones play important roles in agricultural ecosystems. Working trees can help minimize adverse effects of modern agricultural production (Garrett, 1991). Directly or indirectly agroforestry practices can affect wildlife habitat, food safety, air quality, global climate change, recreational opportunities, waste disposal and sedimentation.

Table 1 — Land Cover/Use of Non-Federal Rural Land by State - 1987 (Soil Conservation Service, 1989).[1]

	Crop-land	Pasture-land	Range-land	Forest-land	Other	Total rural land
			1,000 acres			
KS	29,119	2,324	16,660	681	808	49,592
OK	11,557	7,590	14,546	6,505	517	40,715
TX	31,944	17,735	95,204	9,476	2,410	156,769
Total	72,620	27,649	126,410	16,662	3,735	247,076

[1]*numbers may not add correctly due to rounding*

Surface Water Quality

Close to 90 percent of all nonfederal land in the southern Great Plains is used for agricultural purposes. Agriculture-related nonpoint source pollution occurs from irrigated and nonirrigated cropland; concentrated livestock facilities and animal production on rangeland and pastureland (Myers et al., 1985). Sediment, nutrients and pesticides are recognized as the primary nonpoint source pollutants (Chesters and Schierow, 1985; Papendick et al., 1986). Trees are valuable in controlling erosion by increasing soil cover, providing windbreaks, creating weak terraces, increasing soil organic matter and developing a fine root system network (Garrett, 1991). Water quality is improved by the physical buffering capacity of grass and tree strips on sediment and pesticide movement (Lowrance et al., 1985) and riparian forest communities that absorb and retain nutrients (Fail et al., 1987). Vegetative buffers are now being designated as a best management practice around fields receiving animal waste (Safley, 1994) and pesticides (Fawcett, et al., 1992).

Groundwater

Nitrates and pesticides in groundwater are important because of potential health effects when groundwater is used for drinking supplies (Hallberg, 1987). This is of special concern in the Great Plains where groundwater supplies about 50 percent of the public drinking water while substantial additional use in private wells occurs in Oklahoma and Kansas (Butters et al., 1992).

Evidence of high nitrate levels and pesticide detection have been documented in the southern Great Plains (Becker, 1994; Bain, 1992). Agroforestry systems which prevent erosion and capture sediment can decrease nutrient and pesticide contamination. Indirectly, practices which help reduce the use of fertilizers and pesticides can also help to maintain groundwater quality. Such practices may include the use of legumes as a nitrogen source; windbreak trees and increased biological diversity which enhance opportunities for integrated pest management; and windbreak designs which help increase the efficiency of irrigation (Henderson, 1992).

The long-term outlook for irrigation in the southern Great Plains is not optimistic based on current consumption rates in the High Plains aquifer. Annual pumpage of 2 to 100 times greater than annual recharge in the southern Great Plains has caused water level declines of over 100 feet over 2,500 square miles (Gutentag et al., 1984). Even farmers acknowledge that the end of widespread irrigation is inevitable and a return to dryland agriculture on many lands may be necessary (Opie, 1993). It is estimated that a return to dryland agriculture on land irrigated from the High Plains aquifer can be expected within the next 10 to 50 years (Johnson et al., 1983). Agroforestry practices, including those that conserve soil moisture and favorably impact microsite conditions, will have a role under these circumstances.

Erosion

Wind erosion is a severe problem on about 12 million acres in the southern Great Plains and the coarse textured soils in western Kansas and Texas have been identified as some of the most susceptible to wind erosion (Lyles, 1976). Estimated annual average wind erosion on cultivated cropland are 3.8, 4.4 and 11.8 tons per acre per year for Kansas, Oklahoma and Texas respectively (Soil Conservation Service, 1989), which are higher than the 3.6 tons estimated as the national average. In the southern Great Plains, a primary agroforestry opportunity is the increased use of windbreaks, especially important on dryland farms where erosion can be more pronounced than on irrigated farms (Davis, 1989). This could be especially critical on the Dalhart sandy soil area in northwest Texas and Oklahoma and southwest Kansas where heavy irrigation has stemmed wind erosion (Johnson et al., 1983). Additionally, riparian forest management (filter strips) and restoration can prevent sediment delivery to aquatic ecosystems (Maggette et al., 1989; Robinson, J.L. 1991).

Air Quality

Air quality can be affected by agricultural operations and practices that produce excessive dust, chemical drifts, objectionable odors and other emissions. More than 4.1 million cattle are produced in feedlots in the southern Great Plains representing more than 40 percent of the total in the United States (Eghball and Power, 1994). Windbreaks that minimize the movement of air is an agroforestry practice that may be used to address some of the situations in concentrated feedlot operations. Field windbreaks and alleycropping alternatives integrated into overall farm management planning and cropping patterns represent opportunities to address wind erosion and drift concerns.

Riparian Zones

Human activities have severely affected riparian areas in the southern Great Plains. These activities have included irrigation diversions, stream channelization, overgrazing by livestock, land clearing for agriculture, and increased recreational activity (Schmidly and Ditton, 1978; Barclay, 1978; Starkey et al., 1982). Results have been changes in the rates and amounts of water flow, pesticide buildups, erosion, vegetation loss and changes in both floral and faunal composition. A growing body of literature is showing that riparian forests can be effective in reducing nutrients and bacteria reaching water resources

(Peterjohn and Correll, 1984; Fail et al., 1987; Osborne and Kovacic, 1993; O'Neil and Gordon, 1993), acting as a sink for sediment from agricultural lands (Lowrance et al., 1984,1986) and reducing pesticide concentration in runoff (Rhode et al., 1980). There are about 138,462 lineal miles of riparian area streambank without trees or shrubs in the southern Great Plains (Table 2). A major challenge exists to reverse the trend of losing well functioning riparian areas, repair previous damage, and to establish riparian forests where they previously existed (Great Plains Agricultural Council, 1993).

Playa Lakes

One of the unique landforms in the southern Great Plains are the playa lakes; shallow, plate-like depressions that drain internally and periodically flood. About half of the 50,000 playa lakes in the world are located in the southern Great Plains (Nelson et al., 1983). Playa values and uses include providing localized sites of ecological diversity; wintering sites for migratory waterfowl; opportunities for hunting leases; and important recharge areas for the High Plains aquifer. At least 70 percent of all playas 10 acres or larger have been altered for irrigation purposes while half of all the playas are used for livestock grazing (Bolen et al., 1989; Rude, 1991). Environmental concerns include loss of playa vegetation due to grazing and conversion to cropland; loss of wildlife habitat from dicing and burning; runoff from chemical-laden irrigation water; feedlot runoff; decreased flooded areas from pits and increased sedimentation and organic nutrients from reduction in vegetated buffers (Bolen et al., 1989; Guthery, 1979; Nelson et al., 1983).

Table 2 — Lineal Miles of Riparian Area Streambank Without Trees or Shrubs in the Southern Great Plains.

State	Width of Riparian Area (feet)		
	< 100	100-500	>500
Kansas	23,842	3,732	549
Oklahoma	29,172	3,251	769
Texas	67,353	8,632	1,162
Total	**120,367**	**15,615**	**2,480**

Agroforestry practices that control erosion, increase irrigation efficiency and provide for wildlife habitat can address environmental concerns related to playas.

Wildlife and Fisheries Habitat

Changes in U.S. agriculture from the 1940's to the present have caused many wildlife species to decline in numbers. Intensive farming that favors specialization in one or two crops, dependency on chemicals and reduction in habitat variety have been implicated in this decline (Papendick et al., 1986; Robinson, A.Y. 1991). Even fence row vegetation usually produces greater nest densities of both game and non-game birds than do agricultural fields (Best, 1983; Garrett, 1991). Restoration and management of riparian areas, including playa lakes, may provide the most significant opportunity for improvement in wildlife habitat in the southern Great Plains. Erosion control policies that maintain soil productivity and improve water quality also tend to enhance upland wildlife habitat (Miranowski and Bender, 1982).

Sustainability Concerns in the Region

Fundamental issues are at the heart of the sustainable agriculture debates. Struggles for agricultural reform, with related discussions about energy, transportation and health, reflect a broader concern regarding lifestyles and consumption patterns in industrial societies (Dahlberg, 1991). New modes of living which create technological, economic and social balance may be necessary to enhance the quality of life on the Great Plains. This will require a commercial agriculture that is compatible with social and environmental values (Bird, 1993). Agroforestry techniques can contribute to land management scenarios that achieve both production and environmental objectives (Henderson, 1992).

Sustainablility concerns extend across numerous social, economic and environmental sectors.

In the southern Great Plains, agricultural sustainability concerns include (1) creating healthy local economies that experience extreme climatic cycles and economic boom and bust periods; (2) ensuring continued soil productivity on the 8.2 million acres of cropland enrolled in the CRP when the 10-year contracts begin to expire; (3) health risks of farmworkers exposed to pesticides; (4) food safety; (5) energy availability and costs and (6) declining water levels in major aquifer systems used for irrigation and drinking water supplies. Agroforestry can play distinctive roles in addressing these sustainability concerns.

Status of Agroforestry in the Region

In the southern Great Plains, there is little purposeful agroforestry in which tree and agricultural components are deliberately managed together. In 1990, a survey was conducted by Winrock International to identify agricultural producers in the mid-south who were participating in agroforestry practices (Henderson and Maurer, 1993). Only 18 producers were identified in the three southern Great Plains states. The majority of the practices listed involved either windbreaks or cattle grazing with tree production. These, however, are common practices in the region. There are a few intercropping and alternative forestry examples used in the region, but mostly on an experimental or individual basis.

Trees and Cattle Grazing

There is extensive grazing of native forage in existing pine and hardwood stands throughout eastern and central Oklahoma, some of which are located within the broad boundaries of the southern Great Plains, particularly the Cross Timber areas. The Cross Timbers occupy 17,700 square miles in Oklahoma and Texas, 75 percent of which is grazed (Austin, 1972). The primary woody species are post and blackjack oak, but bur oak, sycamore, black walnut, pecan, elm and hackberry are common, especially along the water courses. Excellent growing stock of red cedar is also present. Although incipient agroforestry is practiced through grazing forest-range, few landowners actually manage these resources together deliberately.

Black Walnut Systems

Black walnut is a noted high value timber species and is also used for nut production. Research in Missouri has indicated that timber combined with nut production, grazing, hay, soybeans and winter wheat in varying combinations represent viable alternatives to timber production alone (Garrett and Kurtz, 1983; Kurtz et al., 1984). Black walnut plantations are also considered an economically viable option for conservation reserve lands and other marginal agricultural lands within the corn belt (Noweg and Kurtz, 1987; Garrett et al., 1991). Multicropping management of widely spaced walnut trees with forage intercrops could be applicable to about 500,000 acres in Kansas and over 400,000 acres in Oklahoma and Arkansas (Dey et al., 1987). While the long-term nature of tree planting is risky to the landowner, the reduced capital and labor requirements (compared to row-cropping), flexibility in marketing and diversification are potential benefits (Noweg and Kurtz, 1987). No evidence indicating application of these alternatives by landowners in the southern Great Plains was found.

Pecan Systems

About 775,900 acres or almost 93 percent of the native pecan acreage in the United States is located in Kansas, Oklahoma and Texas (Thompson, 1991). These states also have another 217,900 acres or 40 percent of the nation's improved pecan orchards. The native pecan stands are found predominately in riparian areas throughout Oklahoma and into central Kansas and Texas (Smith, 1950). At least 12,000 acres of commercial pecan acreage is found in west Texas (Helmers,

1993). Grazing under nut-yielding pecans has been practiced by landowners for many years and has become an accepted agroforestry practice, especially for native groves (Kniffen and Wright, 1993). In south central Oklahoma, excellent animal performance has been obtained under pecan orchards while accomplishing the additional goal of understory vegetation control (Mitchell and Wright, 1991). However, a pasture rotation system must be provided to keep livestock out of pecan orchards during and following pesticide applications. Even so, a majority of native pecan orchards are combined with cattle grazing (Smith et al., 1994).

Legume cover crops under pecan orchards may represent a multi-benefit agroforestry practice by supplying nitrogen and increasing arthropods in the orchard that may help control certain pests (Bugg and Dutcher, 1989; Smith et al., 1994). One producer in Oklahoma saved the cost of pesticide applications after establishing legumes (Crummett, 1993). Intercropping pecans with agricultural crops is also a potential agroforestry opportunity. In Oklahoma, intercropping peaches into a new pecan orchard showed that early returns from peaches could be produced but that reduced pecan trunk growth was evident after five years (Smith et al., 1989). There is no evidence of extensive use of intercrops under pecan orchards in the southern Great Plains.

Christmas Trees

Christmas trees are produced on over 5,000 acres in the southern Great Plains. Agroforestry alternatives involving Christmas trees can occur using Christmas trees as an intercrop or intercropping between Christmas trees. As one example, Christmas trees and cattle can be grown economically on the same land with the use of electric fencing to protect the trees (Pearson, 1990). However, this alternative was recommended only to farmers already in the livestock business. One rotation of Christmas trees may be an acceptable intercrop under newly established pecan orchards although such an operation would decrease opportunities for grazing.

Traditional spacing of Christmas trees prohibits effectively intercropping between rows throughout the rotation. One Kansas-based study showed that muskmelons could be successfully relay-intercropped in young Scotch pine grown for Christmas trees (Lamont et al., 1993). Another possibility that has not been adequately explored is using geese for weed control between Christmas tree rows. This procedure was effectively used for a short period of time at the Kerr Center for Sustainable Agriculture in Oklahoma.

Windbreaks

Tree windbreaks are planted on the southern Great Plains primarily to protect soil and crops from the wind. Secondary benefits include wildlife habitat, improved snow distribution, improved crop yields, increased biological diversity, adaptation to climate change, fuels and wood products, recreation and aesthetic benefits (Kort, 1988; Bagley, 1988; Rietveld and Montrey, 1991). In addition to field plantings, windbreaks are also planted to protect farmsteads, livestock and transportation routes (Brandle and Hintz, 1988). Although extensive research showing positive benefits to crops that are grown in the southern Great Plains (winter wheat, hay, corn, vegetables) have been documented around the world, very few studies record results actually obtained in the southern Great Plains (Baldwin, 1988; Kort, 1988; Norton, 1988). In one example, Barker et al. (1985) found that windbreaks increased plant height, bolls and biomass in cotton raised in Texas.

Comparisons of the 1987 and 1982 National Resources Inventory indicate that both farmstead and field windbreaks have decreased in the southern Great Plains (Table 3). The number of farmstead windbreaks decreased by 1,847 representing 2,080 less acres and 333 less miles of windbreaks providing energy conservation, wildlife habitat, noise barriers and beauty. Field windbreaks decreased by 3,173 representing a loss of 7,581 acres and 1,096 miles. The results of these trends were evident in the mid to late 1980's. Almost 2.5 million acres of land were

Table 3 — Estimated Number, Area and Length of 1982 and 1987 Farmstead and Field Windbreaks in the Southern Great Plains.

		Number of Windbreaks		Windbreak Acres		Windbreak Miles	
		Farmstead	Field	Farmstead	Field	Farmstead	Field
Kansas	1982	30,125	51,961	31,288	91,112	3,791	17,690
	1987	28,635	49,348	29,302	84,645	3,491	16,750
Oklahoma	1982	5,400	12,350	3,306	28,314	580	3,721
	1987	5,031	11,924	3,229	27,316	559	3,600
Texas	1982	4,326	3,338	2,546	13,375	531	1,184
	1987	4,338	3,204	2,529	13,259	519	1,149

damaged by wind erosion in Texas in 1988, up from 1.6 million acres in 1987 (Johnson, 1988). In 1989, over 5 million acres were damaged in the winter wheat region of Kansas (Kuhn et al., 1991).

Windbreaks for livestock protection have received inadequate attention in the southern Great Plains (Fewin, 1976). By reducing wind speed and wind chill, feedlot and livestock windbreaks can reduce stress, injury and death of beef and dairy animals, swine and sheep (Hintz, 1983, McArthur, 1991). Windbreaks may also reduce winter feeding costs in feedlots by 10-15 percent (Kuhn et al., 1991) although little research on windbreak influences on the feedlot environment and associated beef gains have been documented under southern Great Plains conditions (Fewin, 1976). Potential to use windbreaks for livestock protection is substantial in the southern Great Plains as Texas and Kansas are among the leading states in beef cattle production. The southern Great Plains states collectively produce over 4.1 million feedlot beef cattle, 84 percent of which are fed in feedlots with 1,000 or more head (Eghball and Power, 1994).

Strategically located living snow fences allow snow to settle on the lee side of a windbreak rather than blocking a highway or other transportation route. While some living snow fence demonstrations have been established in the southern Great Plains, widespread use has not occurred. In Oklahoma, 8 demonstration plantings totalling 12,320 feet were established since 1990 (Oklahoma Department of Agriculture, 1991). In Kansas, 24 living snow fences were planted covering 23,690 feet (pers. comm. Jim Strine) while 7 demonstrations in Texas were established along 5,700 feet (pers. comm. Bob Fewin). All states indicated that reluctance by the highway department will be the major barrier to greater implementation. In the southern Great Plains, only Kansas has established a Living Snow Fence Program, a multi-agency effort that establishes living snow fences on private land at no cost to the landowner.

Eastern Red Cedar Systems

Historically, eastern red cedar was found in Oklahoma where it was protected from fire (Bidwell, 1993). With successful fire control efforts red cedar has become a prominent component of Oklahoma's rangelands and forestlands. Survey estimates in Oklahoma indicate that about 1.5 million acres of red cedar existed in 1950 which increased to over 3.5 million acres in 1985 (Snook, 1985). At least 4 million acres of cedar are estimated to exist in Oklahoma today with about 6 million acres expected by the year 2000 (Bidwell and Mosely, 1989). While expansion of red cedar populations reduce forage available for livestock production (Engle, 1985), it also presents new opportunities for timber production. During the last five years, a fledgling industry harvesting and processing red cedar in Oklahoma has been established. Uses for the wood include shavings for animal bedding, oils for fragrances and lumber for furniture, closet lining and novelty products. Where red cedar was once considered a weed, it is now considered a resource as landowners are receiving income from an under-

utilized resource and are beginning to consider how they can integrate red cedar production into their farmland enterprise.

Riparian Management

The role of Great Plains forests in relation to water quality has not received much research or management consideration (Strickler, 1993). While incipient riparian management may be occurring in the southern Great Plains few concrete examples of riparian restoration or agroforestry practice in riparian zones were identified. Funding for the first demonstration of riparian restoration in Oklahoma was recently made available through the Center for Semiarid Agroforestry.

The best example of coordinated efforts to address riparian area management in the southern Great Plains is the Wetland & Riparian Areas Project (WRAP) in Kansas. WRAP was established to help coordinate state wetland and riparian programs and promote public awareness of these valuable areas. It is an attempt to provide a process for interagency cooperation and public education. On Soldier Creek in Shawnee County, Kansas, interagency cooperation resulted in a restoration plan for a landowner that addressed water quality, streambank erosion, wildlife habitat and timber production. Cedar revetments, willow planting for stabilizations and a variety of deciduous trees and shrubs for species diversity were utilized in the restoration plan (Davis, 1993).

Mesquite Systems

The common mesquite of Texas and Oklahoma is a legume that has a seed pod and fixes nitrogen from the atmosphere. It has spread over land that was formerly prairie and now covers over 82 million acres in Texas (Launchbaugh, 1994). The value of mesquite beans as a forage for pasturing livestock including cattle, horses, goats and hogs was recognized in writings during the early 1900's although some Indian tribes historically used mesquite bread as a food staple (Smith, 1950). The mature pods contain about 13 percent protein and contain up to 30 percent sucrose (Felker, 1979). Mesquite leaves may also be nutritionally important as they contain 16 to 20 percent protein and are similar to alfalfa in fiber composition (Launchbaugh, 1994). The mesquite is one of the few legumes capable of fixing nitrogen in semi-arid soils and thus increasing the fertility of these soils (Felker, 1979). Utilization of mesquite pods for ethanol production and mesquite woody biomass for biofuel production also show promise (Felker et al., 1980; 1982; 1983).

Proposed agroforestry systems in the U.S. utilizing mesquite include mesquite to provide nitrogen with prickly pear cactus to produce digestible calories for humans and animals; and nitrogen fixation with mesquite to improve fertility for rangeland and annual crops such as sorghum and groundnuts (Russel and Felker, 1987; Felker, 1988). Substantial benefits from agroforestry systems with mesquite may occur from improved wildlife habitat. Hunting leases on mixed prickly pear/mesquite communities provide several times greater revenue than obtained by cattle grazing (Russell and Felker, 1987) and the potential for more ranchers to begin a fee-hunting enterprise exists (Butler and Workman, 1993).

Other Agroforestry Possibilities

Several leguminous tree species that have historically provided multiple benefits may also provide promise for agroforestry practices in the southern Great Plains. These include honeylocust, black locust, and species of Leucaena.

Researchers have established new tests to examine the viability of establishing honeylocust in operating pastures. Potential rates of return for pasture honeylocust plantings, based on conservative assumptions, range from 9 to 24 percent (Wilson, 1991). Planting honeylocust could help reduce soil erosion by increasing the profitability of livestock grazing as an alternative to traditional row crops. Although the most viable alternatives for using honeylocust appear to be for wind-

breaks and pod production for animal feed, other alternative outputs include leaf and twig fodder; firewood systems and fermentation of pods for energy production (Wilson, 1993).

As a cold tolerant nitrogen-fixing species with a digestibility similar to alfalfa, Black locust is considered a possible temperate zone agroforestry counterpart to Leucaena spp. (Barrett and Hanover, 1991). With a nitrogen-fixing capacity of 33 to 59 kg/ha released nitrogen (Fowells, 1965; Barrett, 1993) black locust has potential as a green manure and mulch. Although no intercropping trials exist in the southern Great Plains, a progeny test to screen black locust genetic material for short-rotation fuelwood plantations was established in Kansas (Geyer et al., 1993) and showed that variation within black locust is sufficient to warrant further selection efforts in the plains states. Current uses of black locust include soil stabilization on eroded sites (about 4,700 acres) and minor firewood plantations.

Leucaena leucocephala, native to Central America, is a well known leguminous plant used widely in tropical agroforestry applications. It has been mainly used for wood production, fuelwood, animal fodder and soil improvement through alleycropping but also for site reclamation, windbreaks, firebreaks, shade, roadside beautification and food for humans (National Research Council, 1984; Brewbaker, 1987). Using current leucaena selections, forage production systems in the United States are limited to areas in California, Arizona, Texas and Florida (Felker et al., 1991). However, leucaena's range could be greatly expanded using leucaena varieties and hybrids adapted to cool sites but with good yields of high quality forage (Bray et al., 1988; Felker et al., 1991; Wheeler et al., 1993). Interest in leucaeana is growing as a result of efforts by the Center for Semiarid Forest Resources in the Caesar Kleberg Wildlife Research Institute at Texas A&I University. At least one landowner has planted several hundred acres of leucaena under pivot irrigation in south Texas as a substitute for alfalfa that cannot be grown due to cotton root rot (pers. comm., Peter Felker).

Need and Opportunities for Agroforestry in the Southern Great Plains

As ecologically-based land use management systems, agroforestry practices help maintain ecosystem diversity and processes which are critical to long-term sustainability and productivity. The need for landowners and land managers to consider agroforestry alternatives is clear. Agroforestry systems can provide land management options which have ecological and environmental benefits while providing sustainable economic gains. The low percent of land in federal ownership in the southern Great Plains helps the prospects of agroforestry adoption as application of agroforestry principles is expected to be primarily undertaken by the private sector (Garrett et al., 1994).

In the southern Great Plains, there is a substantial potential for employing agroforestry alternatives on highly erodible cropland. The 1987 NRI indicates that in the region there are over 27.5 million acres of cropland with an erodibility index (EI) greater than 8. This represents one-fourth of the highly erodible land in the nation. These lands could benefit from application of both windbreak or intercropping systems that reduce wind velocity, protect soil resources, increase irrigation efficiency and improve crop production.

Riparian vegetative buffer strips constitute another agroforestry practice that is arguably the highest priority need. Riparian forest buffers can be adopted on a large scale, have a high probability of success and can be implemented to give immediate results. The 138,000 plus miles of streambanks in the southern Great Plains not vegetated with trees or shrubs as identified by the 1982 NRI is only one indication of the need for this practice. Riparian forest buffers can reduce the effects of traditional agriculture on stream quality while providing wood products and critical habitat for wildlife species. Trees with deep roots may also reduce potential movement of chemicals to groundwater through subsurface flow and protection of recharge areas such as the

playa lakes. A profitable area of research in the future will be to design agroforestry systems in the riparian zone that optimize crop mixes while maintaining adequate buffer effects.

Grazing systems are important to the southern Great Plains. In addition to the 150 million acres of pastureland and rangeland there are significant amounts of forested areas which support grazing including the pine and oak-pine forestland east of the Great Plains and greater than 15.5 million acres of Crosstimbers, red cedar stands and pecan orchards. The 1982 NRI identified almost 1 million acres of forestland in the southern Great Plains states that have a good potential for conversion to cropland and that could produce high-quality forage and wood products. Several species with potential for pasture agroforestry in the southern Great Plains such as mesquite, leucaena, and honeylocust deserve additional investigation.

Intercropping alternatives may represent viable agroforestry options in the southern Great Plains although much research and demonstration must be initiated to document the most efficient designs and potential returns. Approximately 31.5 million acres of pastureland and rangeland in the region were identified by the 1982 NRI as having high or medium potential for conversion to cropland or agroforestry (Garrett et al., 1994). Some of these lands may lend themselves to the production of livestock and wood products under silvopastoral systems. Other lands may become more productive under intercropping systems that produce sustainable income, prevent soil erosion and add to nutrient capital. Intercropping may even be possible with traditional southern Great Plains crops such as wheat, cotton and corn if production systems that fit intensive, highly mechanized agriculture are developed. In China, Paulownia has been successfully intercropped with the above mentioned crops where wide spacings allow favorable crop growth underneath (Van Den Beldt et al., 1994). Nitrogen-fixing trees with open canopies should be investigated for these purposes.

Constraints and Recommendations

A wide range of actions and support will be required to advance agroforestry in North America and hence, the southern Great Plains. The challenge ahead to develop agroforestry as an alternative land management system rests in addressing three major constraints including: (1) lack of both basic and applied quantitative agroforestry research; (2) lack of institutional infrastructures to support agroforestry research, education, extension and application; and (3) lack of public understanding about the benefits of agroforestry. Each of these constraints will be explored briefly followed by some general recommendations for immediate consideration.

1. Lack of Quantitative Agroforestry Research

Research needs include the entire spectrum of understanding including genetic selection for growth and climatic tolerance; species' responses to site characteristics; management practices to enhance yields; and economics and marketing (Fechner, 1985; Lassoie and Buck, 1991). In some cases, such as riparian forest management, baseline data is also needed not only to determine the original amounts of riparian lands but also to accurately depict their current status (Great Plains Agricultural Council, 1993).

Many agroforestry benefits such as cleaner water, erosion control and increased biodiversity accrue largely to the public while the costs are borne by the landowner. Research is required that analyses economic, environmental and social costs and thresholds for pest damage, soil erosion, water contamination and other environmental consequences of agricultural practices. Such information will allow farm managers to evaluate tradeoffs between on-farm practices and off-farm tradeoffs and may lead to increased adoption of agroforestry practices.

2. Lack of Institutional Structures

Both agriculture and forestry disciplines have established institutional structures which support needed research and facilitate development and application of recommended practices. Agroforestry, being interdisciplinary in nature, does not enjoy this infrastructure which represents a barrier to open consideration of agroforestry alternatives even when they are profitable (Batie and Taylor, 1990; Lassoie and Buck, 1991).

Alternative farming practices, such as agroforestry, typically require more information, trained labor, time and management skills than conventional farming (National Research Council, 1989). It follows that dedicated technical advisors are needed to assist producers in adopting agroforestry practices. Yet consistently, field personnel are identified as not possessing adequate knowledge to help producers with implementation of agroforestry practices in general (Garrett et al., 1994) and specifically with riparian forests (Great Plains Agricultural Council, 1993), tree ecosystems and integrated pest management (Dix, 1992) and water conservation and dryland agriculture (Unger, 1983).

3. Lack of Public Understanding of Agroforestry

Few of the general public today have been exposed to agroforestry activities. Although public concerns about modern farming practices and food safety have prompted congressional actions to protect erodible cropland and support integrated pest management efforts, public awareness about the potential for agroforestry to address natural resource and environmental issues is almost nonexistent (Lassoie and Buck, 1991). Increased public awareness of agroforestry opportunities and potentials can easily lead to the impetus for improved agroforestry research support and development of an adequate infrastructure to support its implementation. Conservation education for grades K through 12 and introduction of agroforestry concepts and principles for teachers is an indirect but crucial long-term strategy to support agroforestry development (Bay, 1993).

Recommendations to overcome these constraints include (1) earmarked funds, (2) revitalized leadership infrastructure, (3) modified public agency perspectives and (4) incentives and marketing options. Without the scientific basis to implement agroforestry concepts and principles no amount of coordination, leadership or incentives will produce efficient results. Agroforestry research, teaching and extension suffers from the lack of funding due to disciplinary boundaries. It is clear that monies specifically earmarked for agroforestry will be required to address the lack of quantitative information in this hybrid field and to provide for training of resource professionals (National Research Council, 1989).

Investments in research, teaching and outreach will not produce maximum results without coordinated efforts to facilitate information sharing, pooling of resources and interdisciplinary efforts. Suggestions have been made for a national agroforestry coordinator, a Commission on Agroforestry, an agroforestry advisory board for USDA interagency task forces and regional consortia or centers (Lassoie and Buck, 1991; Garrett et al., 1994). Focused leadership, coordination between agencies and new institutional mechanisms will be required to produce new and flexible collaborative efforts.

Lack of technical assistance is one reason why producers have not adopted existing economically viable agroforestry alternatives. In some cases, those responsible for outreach recognize the potential opportunities but do not have the technical expertise required to provide assistance. Other agency personnel do not recognize the potential opportunities or the economic and environmental benefits of agroforestry systems. Disciplinary boundaries serve to reinforce these shortcomings. Modified public agency perspectives must be developed to support new research and educational initiatives. Some perspectives will be modified by technical training but the process can be facilitated by leadership which institutionalizes agroforestry principles.

Finally, government policies that discourage the

adoption of agroforestry practices must be reformed. Incentives must be provided for landowners to reasonably consider alternative methods which present risk and challenge their management expertise. In the southern Great Plains, over 8 million acres enrolled in the CRP are potential acres for agroforestry practice. Allowing for income opportunities while meeting the requirements for reduced erosion may protect more acres in the long-term than if producers return to traditional practices following their 10-year commitment. Marketing frameworks that provide intermediaries between agroforestry producers and product consumers may facilitate agroforestry adoption and greater access to larger markets. Producers can concentrate on resource protection and enhancing production while others perform marketing and merchandising functions.

Opportunities for successful adoption of agroforestry practices have ecological, economic and social components. Significant adoption of agroforestry systems will not occur until additional quantitative information and demonstration are available and economic incentives change. This will require both substantial public investment and fundamental reforms in academic institutions and government agencies. With improved collaborative efforts and on-farm research that pursue the multiple goals of profitability, productivity and environmental safety, farmers will be able to make agroforestry a traditional practice rather than an alternative.

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Agroforestry in the Southwest: A Rich Past and Promising Future[1]

David A. Bainbridge[2]

Abstract — The native people of the Southwest were intelligent applied ecologists who actively managed the land. They were skilled in the use of fire, hunted and kept animals, selected and planted seeds for annual and perennial crops including many tree crops, and transported and transplanted trees and shrubs. In many areas they relied on tree crops for much of their sustenance, primarily the oaks, mesquites, and pines. A better understanding of their complex agroforestry management practices will improve future resource use in the region.

The major problems in the region that should be addressed in agroforestry development include: poverty and lack of jobs; poor productivity of degraded woodlands, rangelands, and forests; water and wind erosion; loss of rare ecosystems, species, and populations; health problems, esp. diabetes and dust caused lung diseases; and agricultural and forest pest problems.

Agroforestry practices used today include: forest/woodland grazing; fuelwood, biofuel, and fiber from agricultural and forest or range lands; wild harvest (pinyon, mushroom, etc.); riparian enhancement; windbreaks; edible landscaping; intercrops as beneficial insect refuges; and groundwater and irrigation drain water management.

Changing policy, regulations, and incentives to favor sustainable resource management and improving education and research and providing demonstration projects will speed adoption of agroforestry practices. One of the fundamental lessons of this report is the importance of considering systems as a whole rather than in parts. This is highlighted by the the burgeoning wild mushroom harvests. The high demand and high prices for mushrooms are in large part due to the contamination of harvest areas in Eastern Europe from fallout from the nuclear disaster in Chernobyl (Gillins, 1993). Focusing on a wide range of future products makes it more likely that long term management will be profitable. As Bob Heald comments, if the University of California forest had been optimized to fit economic criteria in the 1960's or 1970's it would be less profitable today. Although many trends are quite clear, it is essential to plan for uncertainty and change

History of Agroforestry in the Southwest

One elderly Kumeyaay reported that women gave sprouted acorns to the Kwaipai, or village chief, who selected the planting area. This matches Kumeyaay ownership data that some oak groves were family owned, some band owned, and some open to any tribal member...

Florence Shipek, 1989

Prehistory

The native people of what is now called North America were not "primitive" people who simply gathered nuts, roots, seeds, and berries, hunted rabbits and deer, and caught fish — but intelligent, skilled and knowledgeable applied ecologists who actively managed the land (Anderson and Nabhan 1991; Bainbridge 1992). They did not inhabit a "wilderness" but a well understood and loved home landscape (Gomez-Pompa and Kaus 1992). Although they did not have bulldozers, tractors, and transnational seed companies they

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were skilled in the use of fire, hunted and kept animals, selected and planted seeds for annual and perennial crops including tree crops, and commonly transplanted trees and shrubs. In most areas they relied on tree crops for much of their sustenance, primarily the oaks, mesquites, and pines (Wolf 1945; Bainbridge 1987d; Bainbridge et al. 1990b).

The planting of tree seeds (oak, pinyon, mesquite, walnut, etc.) and cuttings (willows, etc.) and transplanting of these species and many others including palm trees are but a small example of the practices that are largely unknown to biologists and historians, yet these skills were well developed and common (Anderson and Nabhan 1991; Bainbridge 1985a,b,1987d; Nabhan 1982, 1985; Nabhan et al. 1982; Shipek 1989). These crops provided not only food, but medicine, building materials, craft materials, and fertilizer. Medicinal plants were equally well known, and only selected plants are used, a critical factor for proper medication strength (Nabhan 1982, 1985; Felger and Moser 1974). The genetic similarity of the native palms in California's desert (McClenaghan and Beauchamp 1986) doesn't need to be explained as an interesting distribution process of a relict species if the palm is recognized as a cultivated tree (Lawton and Bean 1968).

The management of fire an essential tool for the native people in the Southwest (Lewis 1973; Biswell 1989; Anderson 1993). Selected areas were burned at different times and frequencies to improve hunting, facilitate harvesting, and to produce desired materials (i.e. numerous straight willow shoots for weaving). Burning might be done in the Spring, Fall, Spring and Fall, or on an annual, 5, 10, or 20 year rotation.

That so little is known reflects the persistent cultural bias against the knowledge of native people and uneducated rural people (Bainbridge 1987b; Chambers 1984). Although these people have not been college graduates they were intelligent and outside learning every day, building upon hundreds or thousands of years of observation and experimentation. We have learned the magnitude of what we have lost through studies of the few "primitive" peoples that have survived into modern times. These studies reveal the richness of their knowledge and the complexity of their management practices (Carneiro 1978; Posey 1985; Balee 1987). Forests once considered wild are revealed as created forests, developed by selecting, transporting, planting and managing plant materials gathered from extensive areas. A better understanding of the use and knowledge of tree crops by the native people of America is overdue.

Agroforestry Use in the Development Period

The complex polyculture of the native people was replaced by resource extraction with a much narrower focus, including intensive trapping, grazing, logging, market hunting, fuelwood extraction, mining, and agriculture. Many of these were combined use at first, i.e. fuelwood cutting on range, fish harvest and timber, and would fit under an agroforestry definition but most were not concerned with sustainability.

Cattle arrived in the Southwest region around 1650. Mission San Luis Rey in Southern California had over 60,000 head by 1829 (Burcham 1957). There were as few as 5,000 cattle in the Arizona Territory in 1870, but more than a million by 1890 (Sheridan 1981). In New Mexico there were 1 million by 1882 (Choate 1966). Much of the Southwest range, woodland, and forest was severely damaged at that time and has never recovered.

Logging began early in California to meet the demand for mines and supply centers such as San Francisco. Early logging to provide lumber, fuelwood, railroad ties, mine props and timber was concentrated near rivers, the coast, near cities and mines, and along the railroads. The most dramatic change came in the post-war years with the introduction of bulldozers (Raphael 1981). Efforts to improve forest regeneration began in the 1930's with the Lumber Code Authority and have continued to evolve with increasing environmental protection and review of sustainability (Raphael 1984; CDFFP 1994). Timber harvesting in New Mexico and Arizona increased at the end of

World War I and has continued at significant levels (Baker et al. 1988).

More than a half million beaver were taken out of the Southwest between 1824-1846. Their removal destabilised streams and watersheds. Hunting and fishing pressure also increased quickly with the mining boom. Fish were once so plentiful in some areas of Arizona that they had to be pitchforked out of irrigation canals to maintain flows (Rinne 1993).

Fuelwood cutting was easily integrated with range, farming, and timber harvesting. In areas where pinyon and juniper were cut the removal was permanent (Young and Budy 1979), but less permanent damage was found in evergreen oak woodlands (Bahre 1991). Pressure on riparian species, mesquite, ironwood, and deciduous oaks has been more damaging.

Regional Description

Even though few, if any, areas in the United States have escaped the transforming hand of humans, few ecologists have identified and analyzed the anthropogenic factors that have influenced the development of the present vegetation cover, let alone whether the changes are short-term or directional, or whether they reflect past or continuing disturbances.

Conrad J. Bahre 1991

The Southwest Region has been radically transformed in the last 200 years. These changes have been so dramatic in many areas that it is hard to imagine the way things looked as recently as 1850. These changes are little studied and poorly understood, and trends such as invasion of brush into degraded range and changes in forest health are not well documented.

Climate

The climate in the Southwest region ranges from some of the hottest deserts on earth to cold alpine environments. Coastal areas that are virtually frost free allow bananas to be grown in California. Some of the key climate zones include the citrus areas in Arizona and California, the date zones in California, the ponderosa forests of Arizona and New Mexico, and the very mild and long growing season climate zones of central and southern California.

Rainfall for the region varies from less than 3 inches per year in the low desert of California to more than 40 inches in the mountains of California (USGS 1970). The predominant climates in the region are classified as either or semiarid or arid. Rainfall patterns vary regionally, with both winter and summer precipitation in much of Arizona and New Mexico and predominantly winter rains in much of California.

Soils

Soils result from the long-term interactions of climate, vegetation, and fauna on the material provided by geological processes (Jenny 1980). One of the most distinguishing characteristics of the soils of the Southwest region is their great variability (Fuller 1975). They include shallow stony soils on mountain slopes, almost pure sand in desert washes and dunes, heavy clays in playas, deep fertile soils along rivers, peaty soils in the delta of California and saline, sodic, and alkaline soils around playas and sinks.

Many soils in the Southwest region appear lifeless much of the year but living organisms, from bacteria to animals and plants strongly influence their fertility and structure. Although they have not been widely studied and are rarely considered by the public and policy makers, small organisms such as ants, bacteria, fungi, microarthropods, nematodes, protozoans, termites and yeasts play important roles in the soil ecosystem. Many of these little noticed organisms are easily disturbed or destroyed by human activity and their elimination can lead to undesirable changes in soil moisture relations, soil fertility, and plant and animal communities.

Vegetation can have a very beneficial effect on the chemical and physical properties of the soils of the Southwest. Nutrients and organic matter accumulate in the surface soil beneath the canopies of desert perennials from the decomposition of litter.

Bioregions

The Southwest region includes the greatest variation in elevation and climate in the United States. Elevation ranges from 282 feet below sea level in Death Valley to more than 14,000 feet in the Sierra Nevada. Most productive agricultural land is in the low elevations with most productive timber land above 4,000 feet. A regional map of bioregions are depicted in Figure 1.

Arizona can be divided into four major geographic zones: plateaus, desert and plains, mountains, and shrub steppe. The plateaus occupy the north and northeast; the desert and plains, the south and southwest. A wide band of mountain ranges separate much of the plateaus from the desert and prairie zones. Shrub steppe is found in the southeast (Conner et al. 1990). Arizona's primary vegetation types and their rough elevation limits include: the creosote bush and mesquite-palo verde scrubs, the oak woodland from 4,500-5,500 feet, pinyon-juniper, ponderosa pine from 6,500 to 8,000 feet, Douglas-fir above 8,000 feet, and spruce-fir above 9,500 feet (Spencer 1966; Brown 1982; Everett 1987; Walker and Bufkin 1986; Eyre 1980; Ffolliott et al. 1992).

California contains a tremendous range of environments and the bioregions range from the hot-dry low desert of eastern California to the Mediterranean climate coast and the Sierra Nevada mountains. Major woody vegetation provinces of the state include desert scrub, Mediterranean climate scrub, oak woodlands, pinyon-juniper woodland, ponderosa pine (4,000-6500 ft), white fir-sugar pine forest and lodgepole pine forest (Donley et al. 1979; Barbour and Major 1977; Plumb and Pillsbury 1987: Standiford 1991).

The landscape of New Mexico consists of open plains and extensive valleys interrupted by mountain ranges. Elevations range from around 3,000 to almost 14,000 feet. The primary woody community types and their rough elevation limits for the state include desert scrub, pinyon-juniper woodland, ponderosa pine forest from 7,000 to 9,500 feet and spruce-fir forest above 8,500 feet (Beck and Haase 1969; Choate 1966; Williams 1986).

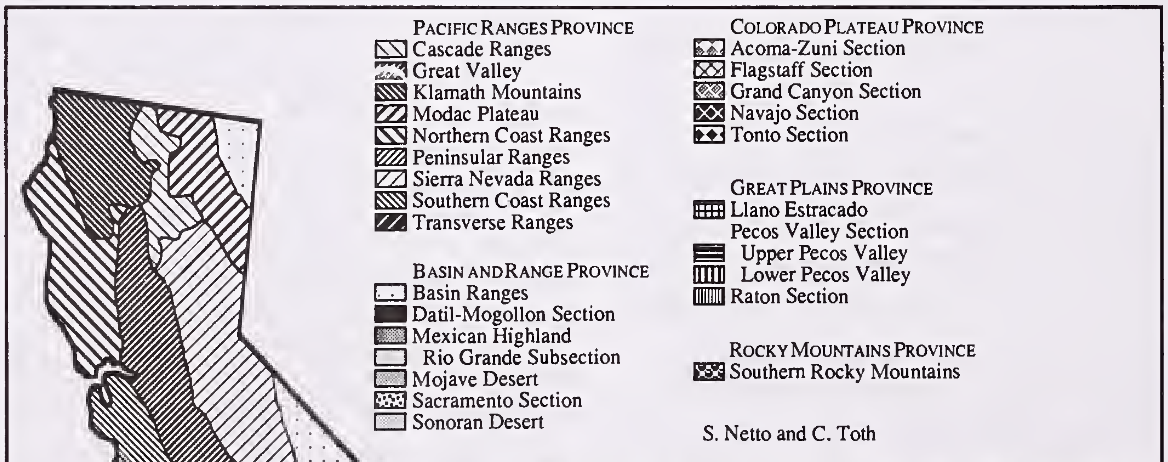

Figure 1 — Bioregions of the Southwest.

Land Use and Land Capability

Land use in the three states varies dramatically, Table 1. Although California is highly developed and urbanized, its farmland is incredibly productive. If considered as a nation it would be the sixth largest agricultural producer in the World (Morse 1994), with hundreds of crops ranging from bananas, oranges, and dates to carrots, rice, kiwi fruits, almonds, and artichokes.

Ponderosa pine (Teccle and Covington 1991) and doug-fir are economically important in Arizona. Doug-fir, larch, hemlock, fir, ponderosa, redwood are important in California (USFS 1978,1980,1989; WWPA 1987). Ponderosa pine, doug-fir, spruce and fir are harvested in New Mexico (USFS 1980; Choate 1966). Many once valuable timber lands are now seriously degraded and/or converted to brush, grassland, or agricultural land.

Changes in Land Use

Land conversion to urban and suburban use is taking place rapidly in the Southwest region (CDFFP 1988; Donley et al. 1991). Development of 5-20 acre ranchettes are removing thousands of acres from farming, ranching, and timber production.

Table 1 — Land use, 1000 acres (Bureau of the Census 1993).

	Arizona	California	New Mexico
Cropland	1,306	10,209	2,297
Pasture	81	1,501	186
Range	31,867	17,719	40,782
Forest	4,912	15,073	4,685

Table 2 — Timberland ownership percent (Bureau of the Census 1991).

	Arizona	California	New Mexico
Federal	66.4	54.2	55.8
State	0.3	0.6	2.2
Private	1.1	44.6	30.8

The remainder is primarily Indian land.

Land Condition

Although various reports are mandated, an accurate land condition survey has not been completed for the region. A clear picture of condition during presettlement days, which would be necessary to determine land condition v/s land potential, hasn't been prepared. The Forest Service (1980) found poor to very poor rangeland condition to be 61% in Arizona, 65% in California, and 70% in New Mexico. Forest condition is better, but less than ideal. In a BLM survey in 1990 only 4% of the 85 million acres of range surveyed was felt to be in the natural community (BLM 1990).

Land Ownership

The three states share many similar habitats and ecosystems but the political landscape and land ownership are quite different. Indian lands are important in all three states, but most economically valuable in New Mexico and Arizona. New Mexico has significant state timber lands, while private lands are important in both California and New Mexico. In all states the Federal land timber holdings exceed 50% of total, Table 2; and decisions affecting Federal lands will critically influence the wood products industry. Many rural counties have as little as 10% private land. This makes government regulation and changes in land management and taxation policy critical.

Principal Environmental Problems

Agroforestry may help address some of the complex and challenging problems facing the Southwest. These include:

Marginal Economics of Rural Resource Management

Poverty is a serious problem in the Southwest, 13 counties in New Mexico have >20% of families

below the poverty line; and in many communities >60% families are below the poverty line (Bureau of the Census 1992a). The tensions over land use restriction and economic opportunity have led to conflicts with the Federal and State land managers from the initial establishment of the Forest Service land holdings (Baker et al. 1988). The "Sagebrush rebellion", "Wise use" and "County sovereignty" movements (Fradkin 1989; Lash et al. 1984; Lancaster 1991; Schneider 1993; Clifford 1994) are the current reflections of this century of conflict.

While some forests are in good health and remain productive large areas have been converted to other habitat types and dramatically altered (Sampson et al. 1994). In parts of the Coconino Forest in Arizona for example, the stem count has increased from 23 trees per acre in presettlement days to 851 trees per acre today (Covington and Moore 1992). Many once productive forest and rangelands have been converted to dense brush, now totaling 14 million acres (Sabadell et al. 1982). Although the general causes, overgrazing, fire control, timber harvest without regeneration, and predator suppression are recognized, detailed understanding is lacking (Milton et al. 1994; Schlesinger et al. 1990).

Extensive areas have been cleared, farmed for a few years, and abandoned. This is not unique to this region but recovery of western lands may take hundreds or thousands of years (Webb et al. 1983; Bainbridge 1990). Jackson et al. (1991) reviewed the abandonment and limited recovery of 2,200 square kilometers of farm land in the Santa Cruz River Valley of Arizona. Problem areas in California include the Antelope Valley (Spitzer 1993), the Owens Valley (Forstenzer 1992); and, if projections are correct, the southern San Joaquin, where many thousands of acres will be abandoned if water subsidies are reduced.

Disruption of the Soil and Hydrologic Cycles

Poor grazing, logging, and development practices can reduce vegetative cover, depress or eliminate palatable species, damage and destroy soil crusts, compact the soil, and increase wind and water erosion. Gross disorganization of community structure in dry lands is possible with the loss of a thin layer of surface soil where nutrients are concentrated (Charley and Cowling 1968). Grazing can reduce infiltration, as much as 90-99% in forested areas, concentrate runoff, and lead to accelerated erosion (Stoeckeler 1959; Anderson et al. 1976).

Dams in Arizona have altered 80% of the stream miles, with catastrophic effects on fisheries (Rinne 1993). Jacobs (1993) provides a clear description of the serious deterioration of rivers in California; where almost a 10 million pounds of salmon were canned in Central Valley canneries each year in the mid 1880's.

Lowering the water table below perennial plant root zones by pumping or channel downcutting has led to major changes in plant communities (Matlock 1976; Sheridan 1981). Invasive weeds and trees (arundo, tamarisk, Russian olive, etc.) have also limited water supply through evapo-transpiration, which may reach 4-13 acre feet year (Davenport et al. 1982). Tamarisk removal has returned water flow to streams (Faull 1993; Duncan 1993).

Fertilizer application in agricultural areas has led to serious contamination of ground and surface waters. Nitrate poisoning and biocide contamination have led to many well closings. Inappropriate water management can also lead to salinization, water-logging, complete loss of production, and problems with selenium and saline tail water (Bainbridge, 1988b; Bainbridge et al. 1988b; 1990a). In several irrigated areas, including the Imperial Valley, virtually all of the land under irrigation is affected (Backlund and Hoppes 1984). The annual cost of water-logging and increased salinity for just one irrigation district (260,000 acres) was estimated to be $17 million dollars (Hanson 1984). Similar problems occur in Arizona and New Mexico.

Air Quality Problems

Abandoned agricultural land, active and fallowed agricultural land without windbreaks,

urban and suburban development, overgrazing, off-road vehicle operation, and water transfers all contribute to dust problems. Particulates are increasingly recognized as a health hazard (Dockery et al. 1993; Schenker, 1993). Blowing dust causes highway accidents in all three states. On Thanksgiving weekend 1991 moderate winds (15-40 mph) caused severe dust and visibility problems on Interstate 5 in Fresno County resulting in a 164 vehicle pileup (Arax 1994). The first settlement with a woman severely burned in the accident cost the state of California $3.4 million dollars, and 36 claims against the state remain to be resolved.

Particulates in the Antelope Valley exceeded the California 24 hour standard of 50 g/m3 of 10 micron particulates almost 10% of the time (California Air Resources Board 1993). These problems from abandoned farmland have been exacerbated sheep grazing (Pyle 1991). Active farmland can also be very dusty, with the state standard exceeded on 24 of 60 observations in Brawley (California Air Resources Board 1993).

In areas with higher wind regimes dust and sand also become physical problems, with drifts and dunes encroaching on highways, housing, farmland and crops, and developments. Removal of sand and dust is expensive. Extensive crop damage is caused by wind blown sand and gravel.

Loss of Rare and Endangered Ecosystems, Species, and Populations

Biodiversity and the protection of rare and endangered species has become an increasingly important element of resource management planning. Unfortunately the limited understanding of the distribution of species, ecosystem structure and function, and trends and changes over time has made protection of biodiversity very difficult. Many basic questions involving underlying science and public policy are unresolved (Westman 1990). One of the biggest problems in the Southwest has been the lack of undisturbed reference areas, unaffected by human actions.

Mature ecosystems often support unique assemblage of species, ranging from bacteria and fungi to birds. Very little old growth is left in the Southwest region (Kanamine 1994; Kaufmann et al. 1992). The rare wetland and riparian areas in the Southwest region are support a wide diversity of species and unique ecosystems. California has lost almost all of its wetlands and most of its riparian ecosystems (Warner and Hendrix 1984; Jacobs et al. 1993). Arizona and New Mexico have also lost most pristine wetlands, and extensive riverine habitat has been turned to dust by water diversion and watershed degradation (Rea 1983; Tellman et al. 1993).

Most discussions have focused on single species, considered rare and therefore endangered. The spotted owl illustrates the potential hazards involved in making large policy issues about almost unknown species (Easterbrook 1994; Verner et al. 1992). Ecosystem protection is likely to prove essential for species protection.

Invasive Plants

Non-native plants have been introduced to the Southwest region since the first humans arrived. The arrival of the Spanish with very competitive Mediterranean weeds species was disastrous. By 1860 as many as 91 important alien species had become established in California (Burcham, 1957). For an overview of the problem see Mooney and Drake, 1986.

Health Issues

Diabetes

In the Native American communities of the Southwest diabetes is endemic. Between 1958 and 1987 the incidence of diabetes related mortality increased 550% in New Mexico's Native American women and 249% in men (Carter et al. 1993). In a Navajo community incidence of non-insulin responsive diabetes was 10%, much higher than the national average (Sugarman and Percy

1989). The traditional native foods rank low in glycemic index and are especially good for diabetics (NS/S Diabetes Project Staff, 1993). Glucose is considered 100, acorns are 16, mesquite flour is 25, compared to potatoes and rice 66-72.

Lung Disease —Particulate Matter

The extensive dust problems in the Southwest are increasingly recognized as a health threat. Particulate matter less than 10 microns in size is able to reach the smallest sections of the lung and is not cleared from these small airways. It appears these small particles may be among the most hazardous air pollution problems (Dockery et al. 1993).

Coccidioidomycosis (Valley Fever, Desert Rheumatism)

Valley Fever is an infection caused by a soil fungus *Coccidioides immitis.* (Pappagianis, 1988; Rippon, 1988). The arthroconidia, which are infectious, can become airborne and remain suspended in air for many hours or days. Valley Fever is endemic in parts of California, Arizona and New Mexico (Pappagianis 1988; Rippon 1988; CSDHS 1994). Dust control in agricultural regions could reduce costly infections and deaths.

Agricultural Pest Management

The final environmental problem that may be partially addressed by agroforestry is pest management. Monocultural crop systems are much more vulnerable to pests than complex systems. Agroforestry practices can return complexity to ecosystems, providing habitat for beneficial insects and birds and reducing the use of chemical controls (Bugg et al. 1991; Altieri 1991).

Current Status of Agroforestry in the Region

Not everybody can be lucky enough to own land for raising both animals and timber. If you have a bad year in animals—coyotes or disease or severe bad weather kills off a bunch of your animals —you can say, "Well I got logging coming this summer". If you own the property and if you have the right attitude about logging and ranching you are controlling your own destiny.

Gordon Tosten, California rancher/logger (Raphael, 1981)

A detailed field survey and interview process is needed to adequately profile current agroforestry practices in the Southwest region. A review of literature and discussions with managers and advisors in both private and public lands made it possible to suggest the nature, though not the full extent or current economics, of these practices.

Forest and Woodland Grazing

The primary agroforestry use in the Southwest region is grazing in the forest or woodlands. This practice has continued since the earliest settlement. The Southwest region demonstrates both the adverse effects of poor grazing practices on timber, woodland, and riparian areas (Sheridan 1981; Chaney et al. 1990); and the beneficial effects of good grazing management (Raphael 1981; Heald 1994). Research at the University of California's Blodgett Forest in the Sierras has demonstrated that well-managed grazing with cattle can provide weed and brush control more economically than either herbicide or hand grubbing (Heald 1994). Currie et al. (1978) found that light to moderate grazing from mid-June to mid-October was compatible with natural ponderosa pine regeneration and more damaging to seedlings planted at 12,000 trees/acre in a summer rainfall area.

Sheep have also been successfully used for weed control in timber plantations in the Sierra Nevada forests and pine plantations in New Zealand (Davies-Colley 1973). Goats are regularly used in the Southwest region to control brush and maintain fuel breaks (Green and Newell 1982).

They could be more widely used to convert brush fields back to timber. They are most effective when controlling brush regrowth after cutting or fire (Huss 1974).

Management of grazing duration, intensity, and timing with close supervision can increase profits and reduce risks. New low cost photovoltaic electric fences have made more precise grazing possible. Careful placement of water sources and mineral blocks can help spread use over a site. Active management may be needed to remove individual animals that develop a taste for young trees. Photovoltaic pumps, hydraulic rams, and ridge reservoirs may improve utilization by providing water away from existing water sources.

Fuelwood

Fuelwood harvest combined with grazing and or timber harvest is probably the second most important agroforestry use in the Southwest. Fuelwood is collected both legally and illegally from public and private forests, woodlands and range. Woodlots have also been economic in California (Donaldson et al. 1988; Klonsky 1988; Merwin 1993). Many of the rural communities in these areas rely on wood heating almost exclusively (Bureau of the Census, 1992b). Data on fuelwood harvest and consumption is difficult to develop (Conner et al. 1990). Estimates include 231,305 cords in Arizona in 1984 (McLain 1988) and 200,000 cords for New Mexico in 1986 (McLain 1989). Akerson (1988) estimated an additional 150,000 cords per year were being used by Native Americans for subsistence purposes in Arizona. If the total is close to 400,000 cords per year in Arizona it represent close to 50 percent of total wood harvest volume. The net value of fuelwood harvest for the Southwest region may approach 100 million dollars. Smaller operators are being replaced by large companies that are much more destructive.

Biofuels

There are currently 800 megawatts of operating biofuel power plants in California, burning 8 million bone dry tons per year, almost 50% from saw mills, more than 20% from agriculture and more than 10% from forests (Biomass Producers Association 1994; Simons 1994). Many of these power plants, an investment of 3 billion dollars and 6,000 jobs, face closure as the ten year power repurchase contracts they operate under end (Simons 1994).

Windbreaks

Windbreaks are used throughout the Southwest (Forestry Division, 1980; RMI, 1988). Windbreak promotion in most cases has been crisis driven, with a short-lived windbreak program following the catastrophic dust storm of 1977 in California (Alcorn and Dodd 1984) and renewed interest after the I-5 highway dust-induced crash in 1989. It appears likely there is currently a small net loss of windbreak length, although living snow fence use is increasing in New Mexico.

In the Coachella Valley of California windbreaks are used to control severe winds and sandblast effects along Interstate-10. One of the longest windbreaks in the U.S. is a tamarisk windbreak along the railroad in the Coachella Valley which provides a very high return on investment. The California Department of Transportation is testing windbreak plantings along I-5 in California's Central Valley along one of the dustiest stretches.

Windbreaks are still being planted for some agricultural crops, primarily high value row and tree crops in high wind areas. Recent windbreaks in the Coachella Valley have done well, being grown-in behind temporary wind fences. Windbreaks have improved grape yield in the Salinas Valley (Dokoozlian et al. 1994).

Fiber

Fiber production from plantations has not been given much attention in the Southwest but interest is increasing as the value of OSB and

other building materials made of once non-commercial trees such as aspen increases. Fiber for paper products is also in demand. The Simpson Tehama fiber farm near Corning, California has planted and experimented with 48 species of trees for fiber production (Regelin 1986; Bacca 1994). Early plantings included sheep grazing during the initial growth stages. Poplar plantations may make sense in areas in close proximity to fiber markets, such as the Sacramento Delta.

Waste Treatment

The use of waste water for irrigation is being explored in Tehama County, and mill wastes are being used in Anderson and near Palermo (Merwin 1994). Land disposal in agroforestry plantings is an integral part of the waste treatment program in Vernon, B.C., and this is an excellent strategy for arid and semi-arid areas.

Wild Harvest

There is a significant but largely unstudied harvest of nuts, mushrooms, berries, and other minor crops. Pinyon nuts are harvested in all three states. Pinyon trees may provide up to 250 lbs of nuts per acre (Van Hooser and Casey 1987) and the total nut crop (some from Nevada) ranges from 1-8 million pounds per year (Lanner 1981; Hamilton 1965; Wagstaff 1987). This represents a retail value of some 7-70 million dollars. Black walnuts are harvested from roadside trees and public lands in California. Acorns and other nuts are also collected (Bainbridge 1987d; Ortiz, 1991). Acorn flour and acorn "jelly" are sold in California, some is produced with California acorns.

Berries, fruits, agaves, cactus pears, and cactus pads are wild harvested in many areas and may reach the market fresh, or more commonly, processed in jams, jellies, or processed. Medicinal herbs are harvested from many areas in the Southwest region. Honey is a valuable product from agroforestry practices in the Southwest. Mesquite honey is preferred and brings a premium at the market. Mushroom harvesting has increased in recent years, and even a remote ranger district may give out hundreds of permits, although the Southwest lags behind the Northwest regions (Molina et al. 1993).

The net value of these minor products is surprisingly high, although these products and uses are unsupported by extension and research and often unregulated. Many of these products are also used for subsistence purposes.

Minor Products and Christmas Trees

The forests and woodlands provide fence posts, poles and other construction materials. In Arizona and New Mexico the cutting of poles for roof vigas is common, little is known of total use and the net value of these products is unknown. Permittees take significant numbers legally. Christmas trees are taken from many forests, both legally and illegally. Even a very modest harvest (1 tree acre/year) would provide greater returns than grazing in many areas (Van Hooser and Casey 1987). Christmas trees are a multi-million dollar business in the Southwest. Many Christmas tree farms also produce other crops, grazing for livestock, and products in agroforestry operations. The average Christmas tree farm in the California Association is only 12 acres (Wade 1994), and many operations are diversified with good potential for agroforestry.

Recreation, Fishing, and Hunting

The value of these uses that can be considered as agroforestry is difficult to calculate. Many ranches now include recreational opportunities such as hunting, riding, or fishing as part of the ranch operation. These activities can be integrated with timber harvest, and fuelwood gathering to provide better forage and feed for game. Elk hunting is particularly attractive, but pig, deer, turkey, and bear hunts are common. Considerable efforts have been made to protect and improve

lands in the Conservation Reserve Program (CRP) program (Margheim 1994). Fee hunting on CRP lands was allowed, and enhancing habitat for game species, including deer, elk, turkeys, trout, waterfowl, and pheasants was common. Much more could be done.

Intercrops

Early farm publications in the Southwest discussed intercrops with trees (Mertz 1918), and the University of California's Sustainable Agriculture Research and Education Program (Halprin and Chaney 1993) is currently evaluating intercrops (65 species) with walnuts and (8 species) with almonds. Crops are often harvested between rows during the first few years of tree establishment or grown as cover crops to improve fertility and reduce weed competition. Intercrops and borders can also provide habitat for beneficial insects. Cornflower Farms (1994) in Elk Grove, CA provides a useful guide to the beneficial insect/ pest relationships of a selection of plants for farm use.

Some farms in the Southwest have developed more complex modern agroforestry intercrops. One of the more common current examples is the intercropping of dates and tangerines in the Coachella Valley. The overstory of dates provides protection from radiation frost. Other more innovative systems have been developed, including a farm in the Coachella Valley that featured a complex polyculture with integrated date palm, orange, pecan, and grain crops with pigs grazed to clean up the waste fruits. An equally effective system in Central California combines an overstory of fruit trees with herb with weed control by weeder geese.

Traditional native American practices continue in some areas, with mesquite trees and mesquite soil used to grow a wide range of crops and support some grazing by chickens. Christmas tree planting has been heavily promoted and widely adopted. Some users combine limited grazing with trees to control weeds. Grazing with weeder geese and other small herbivores may be most appropriate. Limited activity in shelter and shade development for livestock as taken place.

Filter Strips, Buffer Strips, and Watershed Rehabilitation

The use of filter strips to control nutrient and sediment movement into waterways has increased in recent years (Welsch 1991), but have not been widely adopted or promoted in the Southwest region. Buffer strips are included in some detail in all timber harvest plans (CDFFP 1994). These have proved to be very effective (Heede 1990). In Arizona ponderosa pine areas with buffer strips delivered 0.85 kg/ha to streams, while comparable areas without buffers yielded 51.6 kg/ha (Heede 1990).

Several efforts are underway to restore watershed function after years of abuse. These include many riparian restoration efforts in Arizona and California (GAO 1988; Warner and Hendrix 1984; Abell 1989; Chaney et al. 1990; Tellman et al. 1993). One of the best examples of bank erosion control with live cuttings in the Southwest can be seen along the San Miquel and Sonora rivers in Northern Mexico (Nabhan and Sheridan 1977).

Groundwater and Drain Water Management

Trees can be very effective in managing water tables and irrigation drainage water. They may prove to be a vital element in the maintenance of farming operations on irrigated lands in the Southwest (Bainbridge 1987a; Bainbridge 1988b; Cervinka 1987; Cervinka 1994). The benefits trees provide reduced water demand by the crop as a result of improved microclimatic conditions and reduced evaporation from the soil surface (hence less irrigation water is needed); and direct evapotranspiration by the treewhich can reduce drain water volume (see Cervinka paper this volume).

Restoration and Conservation Plantings

Restoration has often been focused on wet-

lands, riparian areas, and rare and endangered species (Abell 1989; Tellman et al. 1993). The recovery program for Clarks Creek in northern California is typical of the work that is being done and needs to be expanded (McLean 1993). Considerable effort is being made in California to improve coordination between agencies and institutions. The Natural Communities Conservation Plan, the memorandum of understanding on California's Regional Strategy to Conserve Biological Diversity (signed by 10 state and federal agencies), and the ecosystem planning work now underway (FEMAT 1993; Dept. of Interior 1994) portend much more effective consideration of these complex issues in the future.

Forest Gardens

The development of complex forest gardens in the Southwest region has reappeared in the form of edible landscaping. The Village Homes Development in Davis, California was one of the first to incorporate edible tree crops on common areas (Bainbridge et al. 1978). More complex forest gardens have become more common (Creasey 1982; Kourik 1986; Bainbridge 1988a; Mollison 1988; Roley 1993). The Aldeas Infantiles orphanage in Tijuana, Mexico demonstrates an agroforestry system for urban areas (Romero 1994). Forest gardens for farm workers throughout the Southwest would have enormous potential to improve living conditions. Urban and suburban agroforestry can improve the utilization of urban and suburban land and resources.

Wood and Craft Products From Range and Woodlands

Most woodland and rangeland has too few trees, smaller size classes, and often non-commercial species, although oak, tan oak, alder, madrone, mesquite, ironwood, and other species are harvested on a limited basis (Rodgers 1986; McDonald 1983; Huber and McDonald 1992; Textor 1994). The increasing availability and effectiveness of bandsaw-based mini-mills and new sawing techniques, like the radial mini-mill (Knorr 1993) may also improve utilization and economics of these species.

The Southwest region also provides craft materials such as willow, for furniture; shoots and roots for basket weaving, and materials for decorative items such as wreaths and interior decorating. These can provide high value added products with minimal investment in tools.

Opportunities For Agroforestry

As the deep-rooting, water-holding trees show their superior crop-producing power in dry lands, we may expect some of our now-arid lands to be planted with crop trees. ...we may be permitted to increase and possibly double our gross agricultural production...

J.R. Smith 1988

It is very helpful to consider the many functions and purposes trees may fulfill when planning agroforestry projects for economic renewal and environmental protection in the Southwest region (Bainbridge 1987c; Fortmann 1990). New techniques have been developed to help establish trees on difficult sites and challenging environments encountered in the Southwest (Bainbridge et al. 1993). Farmers and ranchers will be reluctant to adopt any of these practices until their profitability is demonstrated.

New Jobs and Economic Diversification

Wild Harvest

Wild harvest is likely to be remain the most immediate agroforestry option for creating new jobs in the Southwest. Deliberate management of forests to increase mushroom production may be very profitable. This may include changes in slash management, species mixes, inoculation of seedlings, and fire management. The evaluation of distribution, quantity, quality and market for truffles needs to be reviewed.

A wide range of other berries, nuts, and seeds

are potentially marketable (Ebeling 1986). Expanding the harvests and market for pinyon and pine nuts, berries, mesquite pods and acorns is also very promising (Bainbridge 1985a,1986; Farris 1982; Meyer 1984; Bainbridge et al. 1991). With limited educational support, research, and marketing liaison a wide range of specialty crops — medicine, wine, oil, resins, other foods could become attractive options for wild harvesting and managed production on public and private land. The most economically valuable products are likely to be medicines, which have been little studied despite the dramatic success of traditional medicines from the tropics.

Trees on Cropland

Tree crops on farmland may be interspersed as individuals, rows, hedges, or clusters. Spacing and management will depend on the goals, site conditions, and management. The California Farm Cookbook provides an excellent introduction to specialty producers (Morse 1994), with crops for the growing Asian and Latin American markets of special interest. Among the promising species are mangos, ginkgo nuts, sapotes, jujubes, mulberries, haws, quince, and many more.

In more temperate areas such as the Central Valley timber production from Paulownia, and other fast growing softwoods may prove more profitable (Rao 1986; Brownlee 1988). Paulownia growth in early trials near Fresno has been excellent, with trees at almost 10 meters in 3 years (Robertson 1994).

The value of wastewater use is recognized in Australia, and the guidelines developed there may prove very useful in the Southwest region (Environmental Protection Authority 1983) for establishing and maintaining agroforestry projects.

Windbreaks

Although some windbreak extension information is available in the region (ITCI 1980; Forestry Division 1980), development lags. More widespread use can be expected if economic benefits are clarified and training and extension materials improve. Efforts are now underway to conduct windbreak training courses in California.

Groundwater and Irrigation Drain Water Management

Large reclamation projects with trees have been completed in China and Australia in recent years (Robertson 1985; Biddiscombe et al. 1985). The Victoria provincial government completed a million dollar tree planting program with ground water management as a primary goal (Oates 1983). In the San Joaquin Valley Bainbridg (1987e) estimated that the tree planting requirement for groundwater management might be for about 7.5 million trees on 25,000 acres, a modest amount for forest nurseries that may produce 25 million tree per year. Many benefits can be realized if the trees are carefully chosen (Cervinka 1987;1994).

Fodder

Many species of trees have been used as fodder for livestock and these have excellent potential in the Southwest, including poplars, willows, Leucaena, and some of the Acacias (Treeby 1978; Reid and Wilson 1986; BOSTID 1984). For example, one hectare of Salix matsudana supported 1000 sheep for a week. It may prove possible to provide highly nutritious tree fodder at lower environmental cost and higher profits than alfalfa, a $103 million per year crop in California.

Coppice Crops for Fuelwood and Craft Materials

Coppice and coppice with standards are very promising as a means of producing fuelwood, craft materials, fodder, and environmental protection products in the Southwest. Willows, poplars, and other multi-use crops are of special interest.

Production of ash tool handle wood may also be economically viable.

Trees on Rangeland and Pasture

The most important agroforestry development on rangeland is likely to be shelter for livestock, from searing summer sun and icy winter winds (Reid and Wilson, 1986; Ittner et al. 1958). Design of microcatchment watering for shelter and shade planting is especially promising (Shanan and Tadmor 1979). Howell (1989) has demonstrated the effectiveness of microcatchments for fruit trees in New Mexico.

The open planting of fast growing timber trees is likely to prove economically attractive. This has been explored in some detail in Australia and New Zealand climates similar to parts of California (Reid and Wilson 1986). Nut and fruit trees may also be incorporated on pastureland to improve returns by sale or through use as feed.

Living fences can be incorporated in many agroforestry systems in the Southwest. Candidate species include mesquite, jujube, catclaw acacia, cacti, and yuccas. Timber trees may be used to grow windbreaks and shelterbelts. Trees can also reduce wind damage to crops, cars, and facilities. Demand for both soft and hardwoods is increasing and prices are rising (Luppold and Araman 1988). Mesquite and ironwood, dense woods with excellent stability, may also have excellent potential in the Southwest for the world hardwood market (Madden et al. 1986; Textor 1994). Improved forest management and reconversion of brush to forest may be economically attractive and can be facilitated by grazing and agroforestry practices.

Forest Gardens to Improve Living Conditions

Forest gardens can provide shelter for homes, reducing the cost for heating in winter and cooling in summer. They can also provide much needed food, medicine and income. Trials are needed to suggest designs for low income families and farm workers, suburban homes, public facilities and streets, and rural ranchettes.

Environmental Improvement

Filter and buffer strips

The use of filter strips and buffers can dramatically reduce soil erosion and water pollution in the Southwest. The opportunity for this is greatest in the input responsive high value crops grown under irrigation in California and Arizona. Reducing chemical and fertilizer contamination of water can also make it more likely that chemical controls will remain available longer.

Live cuttings or container stock can be used for erosion control (Gray and Lieser 1982; Schiechtl 1980). Many thousands of stream and river miles need treatment in the Southwest. After plantings are well established beaver can be returned to the stream (Apple 1985). In areas where control structures are needed, cuttings or container stock can be incorporated in the gabions to provide biological flexibility and strength. Watershed revegetation may be needed to stop down-cutting. Land disposal of waste water treated to high standards may be use to recreate riparian vegetation and stabilize stream channels.

Biodiversity/Genetic Conservation

Shelterbelts, hedges, windbreaks, filter strips, and timber plantations can improve habitat diversity and the opportunities for wildlife to feed, live, and nest. Additional information is needed to make development as productive as possible. Agroforestry can improve biodiversity and protect gene pools. Environmental restoration can be a very useful if not essential aspect of protecting rare and endangered species, communities, and ecosystems (Jordan et al. 1988).

Health Issues

Windbreaks and shelterbelts can reduce dust movement and thus movement of the arthroconidia that cause valley fever and particulates (especially PM 10) that aggravate and precipitate other lung diseases. Benefits would be highest in the San Joaquin Valley, suburban areas of lower deserts in Arizona, and southern New Mexico.

Increasing use of wild collected and orchard raised acorns, mesquite pods and other native foods can reduce the adverse effects of diabetes in Native American communities and the population at large (NS/S DPS 1993).

Pest Management

Increasing the structural and species diversity of agroecosystems can reduce pest problems. Beneficial insects can be attracted and protected in shelterbelts and open timber trees and shrubs (Pickett et al. 1990; Altieri 1991). This could be of great importance in California, where chemical controls are being tightly controlled to reduce future contamination of groundwater and damage to human health and ecosystems.

Trees and Transportation

The high winds encountered on many interstate highways in the Southwest increase drag on vehicles and increase fuel cost. Development of shelterbelts and windbreaks can reduce wind speed encountered by traffic and reduce fuel use. A detailed study of the economic return from windbreak energy conservation is long overdue. Windbreaks can also reduce windshield and paint damage, truck overturns, and vehicle accidents caused by blowing dust and snow.

Global Warming

Several actions should be begun immediately to slow and ultimately halt the changes in the global atmosphere. Reforestation and protection of existing forests and active agroforestry development can be helpful. Applied Energy Services in Virginia is off-setting the future carbon emissions from a coal-fired power plant by funding a forest restoration project in Guatemala. Similar incentives might be found to fund agroforestry development in the Southwest.

Problems and Obstacles

The gap between paying now and benefiting later is the biggest challenge confronting improved management of private and public riparian areas.

Chaney et al. 1990

There are many obstacles and problems to improving agroforestry use in the Southwest. Many solutions are relatively well understood and are blocked by institutional and regulatory policies and problems, while many other practices will require detailed economic and environmental research. The major obstacles and problems include:

Emphasis on Technical Rather Than Socio/Political Issues

Environmental and economic problems in the Southwest region involve sociopolitical systems with inter-linkages between social and natural systems; uncertainty over the functioning of both biophysical and social systems, opinions that are very different if not irreconcilable, and funding and political constraints that limit the range of available options. As Forrester (1969) correctly observed, failure to consider systems aspects of problems often leads to treating symptoms rather than underlying causes which often exacerbates the problem as a result of the "counter-intuitive behavior of social systems".

Gladwin (1979, 1983) has laid the groundwork for better appraisal of the adoption of development and environmental restoration programs. Tenure and an optimistic or at least hopeful view of the future are needed for successful agroforestry development. A desperate farmer or rancher near the edge of bankruptcy will find it

difficult to invest energy and resources to plant and see a tree to maturity. Programs of education must reach those who will benefit from an investment in agroforestry. The importance of women in resource management is also frequently overlooked.

Subsidies and Distorted Markets

Economic considerations are the most critical factor in the success or failure of agroforestry systems and sustainable resource management (Mitchell and Bainbridge 1991; Hallsworth 1987). People can rarely be encouraged to do something that is "right" if it is not also economically advantageous (Bainbridge 1985b). There are few fundamental economic laws as there are in environmental science. Economics is a game and the rules reflect special interest's desires and relative power rather than environmental or lifeway concerns.

Distorted markets as a result of subsidies also work against agroforestry and sustainable resource management. The identification and internalization of external costs, e.g. environmental degradation, will be a key element in agroforestry development. The rules that encourage "mining" renewable resources must become much more conservative (Hawken 1993). Tax and regulatory policies with little apparent relation to agroforestry are important; key issues include inheritance and discounting caused by application of operating costs only at the time of sale. Local laws and regulations and institutional (i.e. bank and savings and loans) policies are also important.

Economic development by itself may pose a trap for many communities, as increasing opportunities may draw in skilled, well-educated outsiders. The employment rate and unemployment rate may increase at the same time, with less well educated local residents further marginalized by the development intended to help them. Development must include a careful review of environmental constraints (Sargent et al. 1991)

Ignorance

Simple ignorance is probably the most serious impediment to agroforestry development in the Southwest. The respondents to Lawrence and Hardesty's (1992) Washington survey ranked Lack of Information (27.9) and Lack of Technical assistance (17.6) as the major problems. The first North American agroforestry conference wasn't held until 1989 (Williams 1991). One of the first meetings in California was held in 1986 (UCCE 1986), with a general agroforestry meeting in 1989 (Fortmann et al. 1989), but none of these groups had the resources for followup.

Improving use of existing knowledge is essential because each decision and expenditure has an opportunity cost. Each path taken means another not followed, and each inappropriate or clearly wrong lead pursued makes it less likely that a workable solution will be found. Information on agroforestry is also among the hardest to get. Most of it falls within what librarians refer to as the non-conventional literature, i.e. literature that is poorly distributed and indexed (Mitchell and Bainbridge, 1991).

Over-Specialization

The increasingly narrow focus of education and research in academic institutions is a major contributor to the environmental problems of the Southwest; and the lack of information and expertise in agroforestry, an interdisciplinary topic by definition. This tunnel vision is inappropriate for evaluating, understanding, and designing complex agricultural systems (Bawden et al. 1984; Russell 1982; Bainbridge 1985b; Sands 1986). As Ackoff (1986) comments, "We do not experience individual problems but complex systems of those that are strongly interacting. I call these messes. Because messes are systems of problems, they lose their essential properties when they are taken apart". More commonly the current system punishes those who attempt to deal with these interdisciplinary problems (Schneider 1988).

A secondary effect of specialization is the difficulty of finding funding for innovative research. Federal, state and private organizations are con-

servative and commonly fail to explore innovative approaches, especially integrative programs that step over traditional boundaries. As the National Research Council (1989) commented, "The hallmark of an alternative farming approach is not the conventional practices it rejects, but the innovative practices it includes." Encouraging innovation is essential and will require new methods of reviewing research proposals. Providing support for innovative demonstrations and field trials is particularly important.

The Separation of Knowledge and Experience

The U.S. research and educational system has further compounded the problem of research direction by separating basic, applied, and management research. The increasing attention on problem based learning (Anon 1990; Dodge 1990; Thompson and Williams 1985; Wilkerson and Felleti 1989) may provide the opportunity to return "hands-on" learning opportunities to resource management.

Limited Time, Vision, and Commitment

Funding cycles of typically, one, three, or more rarely five years are incompatible with agroforestry research projects that may take ten, twenty, fifty or a hundred years. The importance of long-term funding has been recognized in only a few programs, most notably the Long Term Ecological Research Program of the National Science Foundation (Callahan 1984).

The relationship between the world view of the observer, the system model developed to explain what is seen, and the manner in which solutions are tested and refined as new observations are made must also be considered (Churchman 1979). What we see depends on who we are and how we look. As a permittee on the Sedow allotment in Arizona commented after being forced to reduce grazing for riparian improvement, the riparian areas had always "looked bad" during his 50 years of use. Yet areas that had been sandy draws were revegetated, verdant, and had flowing water after only 6 years of reduced grazing; and the allowable grazing level was being raised (GAO 1988).

Excessive local influence on land management agencies, which often eliminates efforts to implement or effect changeat the district office level, is another big problem. In riparian restoration for example, the Forest Service has generally been responsive to efforts by staff to improve riparian area, while the Bureau of Land Management had not (GAO 1988). Improved management is usually not a technical but a political problem (Hallworth (1987). Limitations in funding and hiring freezes have left many public management units with inadequate staff to undertake mandated programs (GAO 1988).

Demand For Publications Rather Than Action

Applied long-term interdisciplinary studies must also be better rewarded to encourage progress in agroforestry. Current academic reward systems favor theoretical or lab studies which can be completed quickly and published rather than practical solutions to real problems. Recognizing or rewarding practical solutions to resource management issues is essential.

Recommendations

Small scale, "postage stamp", demonstration projects have proven value for demonstrating the techniques and benefits of improved riparian management. They have helped overcome the inertia of tradition and resistance to change...

Chaney et al. 1990.

The primary goal of this project is to improve environmental management in the Southwest region and to improve economic opportunities, health, and living conditions.

Policy and Programs

Economics

1. Conduct a detailed assessment of existing tax and regulatory policies that provide economic disincentives for agroforestry practices. Diversion of funding for environmentally damaging policies could support program implementation, farm payments to the Southwest exceeded $345 million in 1987 (USDA, 1991).
2. Evaluate the import/export balance sheet for the nation, states, and regions in detail examining potential substitution of tree crops grown in the Southwest region.
3. Conduct detailed economic analyses of agro forestry systems potential in selected areas, including establishment cost, risk, potential income under differing scenarios (see for example Ferguson and Reilly 1978; Scherr 1991a). These should include both farm or site and regional implications. Sensitivity analysis may prove more useful than simple budgeting or cost/benefit analysis for these complex multi-year, multifactor programs (Scherr 1991a).
4. Evaluate potential economic benefits from wild harvest of traditional native American foods on diabetes and effect of wind breaks on coccidioidomycosis and lung disease (PM<10).
5. Establish a cooperative research project with the Traditional Native American Farmers Association to assess economic opportunities from agroforestry.
6. Develop a detailed assessment of the economic costs and benefits of agroforestry and environmental restoration for specific sites and applications, over watersheds, and at the regional level.
7. Develop a model of potential fuel savings from windbreaks along major corridors and contrast to establishment and maintenance cost.

Policy and Management

1. Approach all land management issues from an ecosystem perspective (Tellman et al. 1993; FEMAT 1993).
2. Establish regional agroforestry research centers, based on the very successful program of Precodepa (Niederhauser, 1986), with tasks prioritized and assigned across the range of institutions. (For a discussion within the University of California see Scherr 1991). Private partnerships with NGO's should be sought out and supported.
3. Develop a comprehensive census of the useful trees and agroforestry practices of the Southwest, their ecological, economic, and cultural relationships, and management information.
4. Complete a comprehensive census of useful trees and agroforestry practices for climatic analogs of the Southwest around the world.
5. Develop a program to create forest gardens that can be easily and economically integrated with farm worker housing, neglected city and suburban lands, and schools.
6. Review policy to determine if a Dust Buster program similar to the Swamp Buster and Sod Buster programs is needed.
7. Increase funding for medical research involving traditional medicinal plants of the Southwest region and establish a detailed data base for related species, i.e. the Chinese use of Lycium spp. for cancer treatment. The current work on Acamptotheca, which produces a taxol equivalent, at the USFS Tree Quality Improvement Center in Chico is an encouraging step in this direction.
8. Develop funding for research on herbs and fodder plants and a detailed data base.
9. Review forest policy and practices regulations to remove obstacles to agroforestry. This may include developing new permitting processes for wild harvesting, planting or enhancement on public lands, and different grazing, logging, and recreation practices. Aggressive implementation could provide new sources of income for rural communities and agencies, benefiting both.

Education

1. Create an agroforestry information program to release articles and information to radio and newspapers in the region.
2. Establish an interagency working group (USFS, NSF, BLM, EPA, USDA, OTA) to improve the methodology and foundation of research strategies for agroforestry systems (Scherr 1987; Nair 1993).
3. Develop and support agroforestry extension for farmers, foresters, homeowners, small businesses, and ranchers interested in developing agroforestry systems (Muller and Scherr 1990; Hildebrand et al. 1993). A key first step would be preparing a detailed guide to information (see for example Mitchell and Bainbridge 1991) and The Rudy Grah agroforestry collection (Menzies et al. 1988).
4. Develop an interdisciplinary agroforestry curriculum adapted for the Southwest region. This would provide teachers with a well-developed course material in agroforestry and suggested inter-links with geography, anthropology, forestry, agronomy, range, economics, business administration and soils. (see Genthon 1989; Mooney 1989; Wollenburg 1989; Zulberti 1987).
5. Develop manuals on agroforestry for specific user groups in different bioregions and climate zones. This might include information on exotic fruits for the San Diego mango belt and traditional wild harvesting in the oak woodlands of southern Arizona
6. Develop funding for long-term, inter-disciplinary research, involving basic, applied and management issues.
7. Develop a smart system to identify appropriate agroforestry interventions and predict most probable cost and profit potential.
8. Prepare an agroforestry library package for regional libraries, comparable to the AT library (Baldwin, 1986) or on CD. Key resources should also be abstracted in Dineh, Tohono O'odahm, Apache, Spanish, and other languages.
9. Fund distribution of key journals (Agroforestry Systems; Inside Agroforestry; International Tree Crops Journal; Agroforestry Today; Society of American Foresters Agroforestry Working Group Newsletter; Forests, Trees and People, etc.) for schools, government and NGO's.
10. Develop ecological (Bainbridge, 1985a) and cultural literacy requirements for new positions to foster inter-disciplinary programs in agroforestry with extensive hands-on training. Provide on the job training to upgrade current skills.
11. Support a comprehensive inter-disciplinary review of the rewards and incentives system in academia and development of alternatives that foster long-term, interdisciplinary research, including applied research.

Demonstration

1. Establish regional demonstration windbreaks and shelterbelts, filter strips, intercrops, timber with grazing, fast growth timber, and shelter for livestock on public (Universities, Plant Material Centers, District Offices, etc.) and private lands. Conduct regular tours, short-courses, and workshops.
2. Develop model forest gardens to demonstrate regional differences and benefits.
3. Install a major highway dust control project on Interstate 5 in California, the cost of 10-20 miles should be less than 10% of the one legal judgment against the state of California.
4. Support fast growth timber trials for: Paulownia, poplar, alder, ash, KMX pine, eucalyptus, casuarina, and mesquite.
5. Test fodder plantations for dairy operations (willow, tagaste, etc.).
6. Install water management demonstrations, including keyline, coupled photo-voltaic solar and hydraulic rams with ridgetop tanks, micro and macro-catchments, and flood water irrigation.
7. Support agroforestry demonstration projects on the thousand acre scale for abandoned agricultural land between Phoenix and Tucson and the Santa Cruz Valley in Arizona,

the Antelope Valley and San Joaquin Valleys in California and the Pecos and Chama Valleys in New Mexico.

8. Develop demonstration programs for sustainable management of hardwood resources, i.e. ironwood (Olneya tesota), mesquite, oaks, etc., and specialty crops with in agroforestry plantings (see Henry 1994).
9. Establish small land-holder demonstration/research plots on small land holdings, 5-20 acre), for retirees and subsistence operators.
10. Develop model restoration projects in repre sentative watersheds, based on sustainable agroforestry practices (see Pilarski, 1994).

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Agroforestry and Sustainable Systems in the Intermountain Region[1]

Robert J. Lilieholm[2]

Abstract — The Intermountain Region covers Colorado, Idaho, Nevada and Utah. Although the region's population is low, it is highly urbanized and fast growing. The resulting pressures on the region's resources create both opportunities and challenges for agroforestry practices designed to improve the sustainability of human and natural systems. While the most widespread agroforestry practice is farmstead windbreaks, the region could benefit from additional windbreaks (field, residential and livestock), riparian buffers and filter plantings, tree/shrub plantings to improve fish and wildlife habitat, living snowfences, and increasingly, agroforestry practices designed to ameliorate or mitigate environmental degradation. These practices should be designed to enhance economic opportunities in rural areas, improve energy efficiency and the livability of communities, and improve water quality and wildlife habitat. Regional agroforestry barriers include limited information on agroforestry's benefits, and fragmented institutional jurisdictions. To meet these challenges, this paper recommends a program of research and technology transfer; improved coordination between agencies, universities and the private sector; increased education and training; and new and expanded agroforestry incentive programs that reach beyond traditional resource-based clients to include urban and suburban residents.

Introduction

The Intermountain Region includes Colorado, Idaho, Nevada and Utah. The 377,974 square mile region (978,953 square kilometers) includes over 7.5 million people. While the region's population is low overall, it is highly urbanized and rapidly growing, creating both challenges and opportunities for expanding the role of agroforestry and sustainable land use practices.[3]

Agroforestry practices have the potential to improve traditional food, forage and fiber production systems in the region. This paper describes the natural and social features of the region, assesses the status of agroforestry practices, and explores the opportunities and barriers facing efforts to expand agroforestry's role in fostering the region's economic, social and ecological sustainability.

Regional Description

Natural Features

Six major physiographic provinces are located within the Intermountain Region—the Great Plains, the Rocky Mountains, the Colorado Plateau, Basin and Range, the Snake River

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Lowlands, and the Columbia Basin (Fig. 1). The region's climate is highly variable and is strongly influenced by elevation and a rain-shadow effect from California's Sierra Nevada range. For example, while the region's arid lowlands may receive only 5 inches/year (13 cm/year) of precipitation and be unable to support natural tree cover, higher elevations may receive up to 40 inches/year (100 cm/year) and support dense forests.

The region contains eight major forest types (Douglas-fir, ponderosa pine, white pine, lodgepole pine, larch, fir-spruce, hardwoods, and pinyon-juniper)(Eyre 1980). Like climate, forest vegetation is largely determined by elevation, and Intermountain forests are often bounded by both upper and lower timberlines. For example, much of Nevada, Utah, and southern Idaho are nonforested due to limited precipitation. Pinyon-juniper woodlands, found on low elevation, dry sites, are the major forest type of Utah and Nevada. At the other extreme, fir-spruce forests typically occupy high elevation, more mesic sites. Most of the region's forests are coniferous, although aspen occupies large areas in central Utah and western Colorado. Throughout the region, the majority of forest land is managed by the USDA Forest Service (USDA FS).

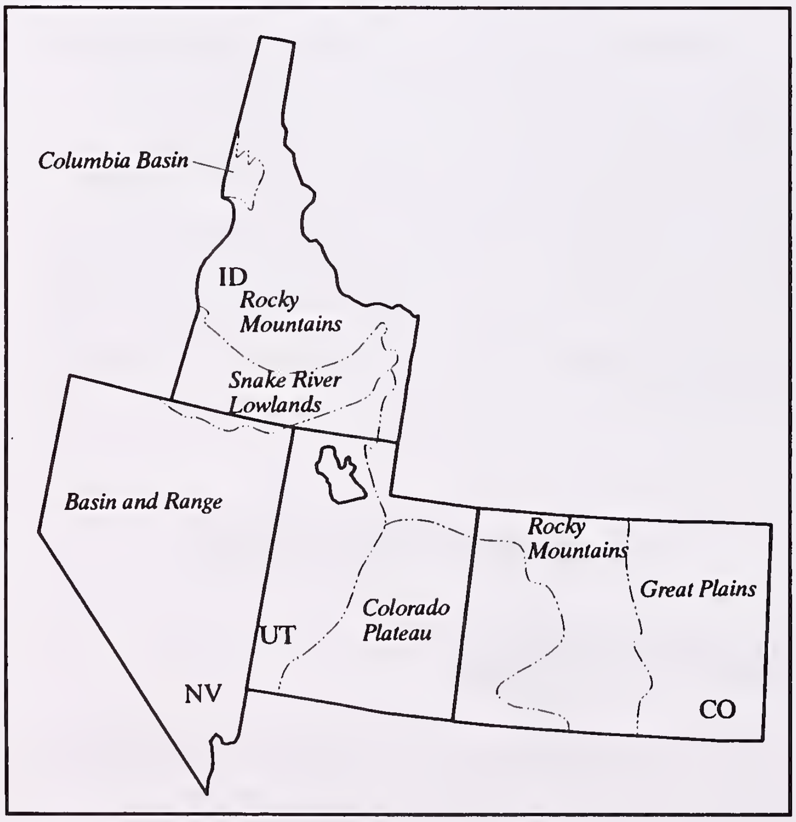

Figure 1 — Physiographic provinces of the Intermountain Region (adapted from Graf, 1987).

Three major non-forested vegetation types are found within the Intermountain Region. The non-forested areas of Nevada, Utah, southern Idaho, and western Colorado are typically covered by the temperate desert Intermountain shrub vegetation type (West 1988). The Intermountain bunchgrass type (Stoddart et al. 1975) once covered much of the area, but it has largely been replaced by sagebrush due to overgrazing and fire control. The short-grass type covers much of the Great Plains in eastern Colorado (Stoddart et al. 1975).

Demographic Features

The Intermountain Region's population was 7,677,000 people in 1992 (The American Almanac 1993). While low on an area basis, the region's population is highly concentrated and growing rapidly. In fact, the four Intermountain states were among the six fastest-growing states in the U.S. between 1990 and 1992 (The American Almanac 1993).

The region's population is highly concentrated in seven fast-growing metropolitan areas. For example, roughly 80% of Colorado, Nevada and Utah residents live in metropolitan centers (The American Almanac 1993). Furthermore, the population growth of these metropolitan centers greatly exceeds that of rural nonmetropolitan areas (The American Almanac 1993). These demographic patterns have strained the region's natural and social infrastructures, and is rapidly altering the region's economy and established land uses.

Federal lands comprise 36%, 62%, 85% and 65% of the land area in Colorado, Idaho, Nevada and Utah, respectively (The American Almanac 1993). Most of these lands are managed by the USDI Bureau of Land Management (USDI BLM) and the USDA FS; tribal land holdings may be large in some areas. Of the region's nonfederal lands, cropland, rangeland and forest comprise the dominant land cover and use (The American Almanac 1993). Most low elevation riparian lands are privately owned.

The region's farms average 577 acres in Idaho, to a high of 3,300 acres in Nevada (The American Almanac 1993). The number of farms declined between 1987 and 1992, as have farm per-acre values over the 1985 to 1992 period. Between 1990 and 1991, farm net income fell an average of 22.5% (The American Almanac 1993). Due to the region's aridity, irrigated lands are widespread, and 80% to 95% of regional water withdrawals are used for irrigation (The American Almanac 1993).

Farm marketings in 1991 ranged from $276 million for Nevada to $3.7 billion for Colorado, with cattle and dairy products generating the most revenue (The American Almanac 1993). Other important commodities include corn, wheat, potatoes, hay and turkeys.

Agroforestry and Sustainable Development

Global concerns over environmental decline and inter-generational equity have spurred interest in sustainable development practices. The Brundtland Report (1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability concerns have expanded traditional production goals to include stability and equity by adopting a cautious approach to managing natural systems, reducing system inputs, and recognizing the human dimension of ecosystem processes (Martin and Prather 1991, Conway 1987).

In the agriculture profession, sustainable development principles have redirected practices to include more environmentally-sound methods. At the same time, the forestry profession has experienced a similar evolution with its adoption of ecosystem management principles (Gillis 1990, Lassoie and Buck 1991). Agroforestry, with its dual goal of production and protection, complements these professional developments.

Regional Natural Resources Concerns

Population growth has heightened concerns over water availability in the arid Intermountain Region. While the vast majority of water is used for irrigation and could eventually be diverted to culinary use, rising demands for in-stream uses to provide fish and wildlife habitat could lead to restricted water supplies and increased prices.

Another emerging issue is the loss of biological resources through habitat destruction resulting from traditional land uses, growing human populations and development pressures. Highly visible species include the threatened Mojave desert tortoise of southern Utah and Nevada, and salmon fisheries in Idaho. Finally, energy conservation continues to be a long-term concern for the region.

Regional Economic Concerns

Declining Natural Resource-Based Industries

Many resource-based economic sectors in the Intermountain Region have declined over the last few decades, seriously impacting rural economies and region-wide demographic trends. While the origins of decline are many, increased global commodity production and falling prices play a central role. For example, inflation-adjusted prices of agricultural and mineral commodities has declined 37% and 26%, respectively, between 1975 and 1988 (World Resources Institute 1990). Timber prices are one exception to the trend, having increased 85% during the same period.

Demographic Changes

The Intermountain Region is experiencing rapid metropolitan population growth while declining natural resource-based economies and limited employment opportunities plague rural

regions. In fact, during much of the 1980s, unemployment in U.S. rural counties was 50% higher than the national average (Le Master and Beuter 1989).

This imbalance not only fuels migration from rural areas, which can weaken rural economies, but also threatens human and natural systems in urban areas. As urban areas expand, rapid development can erode the livability of communities as crime, congestion, and pollution increase. Urban/wildland interface issues also become more critical. Specific concerns include human-wildlife interactions, riparian zone health, soil erosion and water quality, and the risk of wildfire.

The Global Economy

Finally, the recent North American Free Trade Agreement (NAFTA) could profoundly impact land use and demographic trends in the region. For example, as barriers to trade are reduced or eliminated, changing global markets will impact the profitability of new and existing land uses. These changes will in turn affect population demographics through altered employment opportunities and incomes.

More direct impacts may result from two proposed Canada-U.S.-Mexico transportation corridors that would traverse the Intermountain Region—one proposed for each side of the Rockies. The ultimate location of these corridors will profoundly affect the economies and land uses of the region, as well as agroforestry's potential to make contributions to the region's sustainability.

Status of Agroforestry in the Region

In February of 1994, USDA Soil Conservation Service (USDA SCS) foresters assessed the use of agroforestry practices in the Western U.S. Their assessment for the Intermountain states is given in Table 1. Overall, most agroforestry practices are in limited use. Farm windbreaks and trees for production landscaping were the most common practice. The only extensive practice was farm windbreaks in Colorado. Among the four Intermountain states, Colorado has the highest use of agroforestry practices while Nevada has the lowest. Overall, however, the Intermountain Region lags behind California and the Pacific Northwest in its use of agroforestry practices.

Table 1 — Evaluation of tree/shrub plantings in agricultural settings in the Intermountain Region[1]

Agroforestry practice	Landowner activity and trend[2] Extensive	Common	Limited
Row-types			
Farmstead windbreaks	CO+	ID+ NV+ UT+	
Field windbreaks		CO+	ID+ NV+ UT+
Hedgerows (alley crops)			CO+ UT+
Livestock windbreaks			CO+ ID NV
Living snowfences		CO	ID+ NV
Block-types			
Christmas trees		CO+ ID	NV UT+
Cover/habitat plantings		CO+	ID+ NV+
Nut/fruit tree orchards		CO UT+	ID NV
Riparian buffer/filter plantings		CO+ ID+	NV+ UT+
Trees for production landscaping		CO+ ID+ UT+	NV+
Water-uptake plantings			ID UT

[1]*Source: USDA SCS forestry specialists, Western U.S., February 14, 1994.*

[2]*Extensive: many plantings throughout most farm areas.*
Common: a noticeable number of plantings in many farm areas.
Limited: experimental plantings by just a few producers.
Trend: "+" indicates an increasing involvement, otherwise trend is stable. No practices in the Intermountain Region are believed to be on a downward trend.

Within the Intermountain Region, Colorado and Idaho have been most active in promoting agroforestry. In Colorado, a Field Windbreak Campaign (FWC) involving state and federal resource agencies and private individuals has been active over the last eight years in establishing windbreaks and coordinating interagency windbreak-related activities (Olmstead 1994). In addition, the FWC has hosted numerous forums to improve the effectiveness of conservation agencies.

In Idaho, the Idaho Association of Soil Conservation Districts and the Idaho Resource Conservation and Development Association formed an Idaho Agroforestry Coalition (IAC) in 1994. The IAC serves as a mechanism to attract funds for agroforestry programs, enhance existing work, and expand technical assistance to landowners. Coalition cooperators include diverse groups like Pheasants Forever, the USDA FS, and the University of Idaho Cooperative Extension (Kuhn 1994).

Table 2 — Priority agroforestry practices for the Intermountain Region[1]

State	Priority agroforestry practices[2]
Colorado	Field windbreaks, living snowfences, riparian buffer and filter plantings
Idaho	Field windbreaks, living snowfences, riparian buffer and filter plantings
Nevada	Farmstead windbreaks, field windbreaks, riparian buffer and filter plantings
Utah	Farmstead windbreaks, field windbreaks, Christmas trees

[1]*Source: USDA SCS forestry specialists, Western U.S., February 14, 1994.*

[2]*Practices are identified based on their potential to provide an alternative "low impact" land use or mitigate soil, water, air, plant or animal resource problems. Practices are not listed in order of priority.*

Needs, Opportunities, and Barriers to the Adoption of Agroforestry Practices in the Region

Needs and Opportunities

The environmental problems created by traditional land uses and agricultural practices offer significant opportunities to expand the role of trees and shrubs throughout the U.S. (Licht 1993, Rietveld and Schaefer 1991). Long and Nair (1991) believed agroforestry practices could benefit small U.S. farmers by reducing risk through diversification and providing specialty crops. Agroforestry could also alleviate overproduction by removing marginal lands from intensive agriculture and placing them under mixed systems with trees. This practice would aid biodiversity goals as well (Long and Nair 1991).

Lassoie and Buck (1991) assessed the opportunities for agroforestry in North America and divided the potential benefits into three broad areas: ecological benefits (e.g., biological diversity and sustainability), economic benefits (e.g., reducing inputs, diversifying farm products and developing new crops), and social benefits (e.g., revitalizing rural areas and improving land stewardship ethics).

A recent assessment by USDA SCS foresters of the potential contributions of various agroforestry practices in the Western U.S. is summarized for Intermountain states in Table 2. All states in the region could benefit from increased field windbreaks. In most states, the establishment of riparian buffer and filter plantings was identified as a priority. Other recommended practices included farmstead windbreaks, living snowfences and Christmas tree plantings.

The research and outreach programs needed to promote these practices must be carefully considered. For example, urban and suburban residents, often neglected in favor of traditional resource-based rural constituents, increasingly wield tremendous influence over state and regional issues. Rather than view this shift in power as a threat, resource agencies must expand their programs to embrace these non-traditional groups. One way to meet this goal would be to encourage residential windbreaks for energy conservation, aesthetics, and wildlife habitat.

The Intermountain Region's large federal ownerships make federal leadership particularly important for the adoption of practices. But with reductions in agency personnel and declining budgets, significant challenges exist. The adoption of ecosystem management as a guiding management philosophy by the USDA FS and the USDI BLM should be viewed as an opportunity to expand the role of agroforestry in the region.

Tribal lands offer yet another opportunity to expand agroforestry practices. Marginally productive lands, high unemployment, and widespread subsistence land use practices make these areas well-suited for windbreaks and the planting

of multipurpose tree species that provide a mix of products and services.

Finally, existing land uses must be considered when identifying agroforestry practices with a high probability of adoption and success. Irrigated agriculture, livestock production, and urban settlement patterns are the region's three key land uses and thus provide target areas for research, programs, and incentives.

To guide the adoption of agroforestry practices, three broad goals for the Intermountain Region are identified below based on the particular needs and opportunities of the region. These include the adoption of agroforestry practices that (1) provide economic opportunity in rural areas, (2) enhance energy efficiency and the livability of human environments, and (3) improve water quality and wildlife habitat.

Creating Economic Opportunities in Rural Areas

Agroforestry practices that expand economic opportunities are needed in rural areas experiencing declining employment and wages. Such areas could benefit from Christmas tree plantings and multipurpose tree species that provide specialty products, diversification potential, and other benefits (Campbell et al. 1991, Hill 1991). Areas near urbanizing regions can profit from the planting of Christmas trees and trees for production landscaping. Research is needed on these and other diversification strategies, and funds are required to establish demonstration areas and the necessary infrastructure to allow capital-poor rural areas to adopt proven technologies as they are developed.

Enhanced Energy Efficiency and Improved Livability in Human Environments

Programs that aid the establishment of windbreaks for energy conservation and enhanced community livability offer one avenue for serving non-traditional clients. Such efforts are particularly needed in rapidly developing areas, where existing buffers are often eliminated with new construction. Increasing the public's awareness of the environmental benefits of trees could positively influence many state and local programs, and turn potential adversaries into allies in efforts to improve environmental quality.

In addition, agroforestry may be used to improve the profitability of agricultural lands and in turn slow the conversion of open space to development (Long and Nair 1991). Once agricultural lands are developed, however, residual trees from intercropping practices could improve land values for commercial and residential use (Williams and Gordon 1991).

Water Quality and Wildlife Habitat Improvement

Throughout the Intermountain Region there is a growing need for agroforestry practices that improve water quality and wildlife habitat. The USDA SCS evaluation identified riparian buffers as a priority practice for most states in the region (Table 2). Buffer establishment is important for several reasons. First, riparian areas provide important water and habitat for many wildlife species, especially in the arid West. Second, most lower elevation riparian areas are in private ownership and tend to be heavily utilized and developed. Finally, in this fast-growing region, the proactive establishment of habitat can be used to alleviate and/or mitigate future conflicts between economic development and environmental protection.

Barriers to the Adoption of Agroforestry Practices

Lassoie and Buck (1991) identified several inherent constraints to the development and adoption of agroforestry practices in North America. These included a climate that was not conducive to the rapid growth of woody plants,

slow-growing indigenous trees that typically offer limited products, a highly-educated, urban industrial society, and the emergence of very strong but separate agriculture and forestry institutions.

The Intermountain Region faces several additional constraints: (1) environmental factors resulting from the region's aridity (e.g., drought, difficult establishment, and the need for irrigation), and (2) economic factors (e.g., limited availability of capital and limited agroforestry markets, services and supplies). All of these barriers combine to limit information on agroforestry's benefits.

Specific Recommendations

Agroforestry practices could enhance the sustainability of both urban and rural communities in the Intermountain Region. In urban areas, efforts to improve energy conservation and community livability are paramount. In rural areas, agroforestry practices that provide economic opportunity, environmental protection, and enhance the profitability of agricultural practices are needed. To realize these opportunities, four specific recommendations are described below.

Research and Technology Transfer

Much of the research on agroforestry practices in the U.S. has examined silvopastoral systems, windbreaks, and crops with fruit trees or high-value hardwoods (Bandolin and Fisher 1991). Moreover, most of this work has been located in the semi-humid Great Plains, the Southeast or Midwest regions of the U.S. (Lassoie and Buck 1991). Since much of this research has limited application to the region, new studies specific to the region's conditions and needs are required to identify practices with a high probability of adoption and success.

In particular, the effects of windbreaks on irrigated cropland and crops like potatoes and sugar beets needs to be studied. Because of poor design, existing windbreaks offer limited opportunities for scientific study, necessitating the establishment of designed windbreaks or methods that utilize artificial barriers. Also needed are studies designed to identify species suitable for various agroforestry practices. Finally, national symposia and the establishment of demonstration sites is needed to foster awareness and improve technology transfer.

Improved Coordination Between Agencies, Universities, and the Private Sector

Improved coordination between agencies, universities, and the private sector is needed before significant gains in the adoption of agroforestry practices can be realized. Such coordination should strive to remove barriers resulting from fragmentation that exists in natural resource institutions.

Lassoie and Buck (1991), in their strategy for expanding the adoption of agroforestry practices in North America, recommended the creation of regional centers like ICRAF in Africa and CATIE in Central America. In this regard, the creation of the National Agroforestry Center (NAC) in the 1990 Farm Bill was a major step in the recognition of agroforestry's role in improved land use in the U.S. Toward this end, the activities of the NAC should be expanded throughout the Intermountain Region and other Western states.

Alongside this federal effort, state and local institutions need to identify local opportunities and develop communications links with landowners. Within this framework, the Land Grant Universities must play a critical role in education, training, extension and research. Specifically, universities need to redirect their focus to study temperate zones and examine a broader array of systems (Lassoie and Buck 1991).

Finally, working partnerships between government and the private sector are needed to explore new agroforestry methods, establish demonstration areas, and create new markets and services. For example, increased landowner recognition would fuel demands for specialized

agroforestry supplies like nursery stock, mulches, and various contractor services. Specialized nurseries could expand economic opportunities in rural areas while relaxing shortages of some agroforestry species.

Increased Education and Training

Opportunities for educational training in agroforestry are currently limited in the Intermountain Region. Educational opportunities should be expanded in three critical areas — training opportunities for extension, agency and technical personnel, training opportunities for landowners, and an expansion of agroforestry-related undergraduate and graduate education programs at the region's Land Grant universities.

For extension personnel, increased training and the hiring of agroforestry specialists is needed to improve the adoption of agroforestry practices in the region. Extension programs and short-courses that educate landowners about agroforestry's benefits are needed as well.

The region's Land Grant universities are rapidly developing courses and research programs in ecosystem management and sustainable agriculture. There is currently a limited offering, however, of agroforestry courses and programs. Furthermore, most existing courses study agroforestry applications in the tropics rather than those relevant to the arid and semiarid U.S. While interest is increasing at both undergraduate and graduate levels, improved agroforestry employment opportunities are needed for continued program development.

New and Expanded Agroforestry Incentive Programs

The immediate costs and broad social benefits of many agroforestry practices requires that access to capital, tax incentives, cost-sharing, and low-cost professional assistance be available before landowners will adopt agroforestry practices (Long and Nair 1991).

Several programs are already in place to aid the establishment of agroforestry practices. These include the Forestry Incentive Program, the Stewardship Incentive Program, the Agricultural Conservation Program, and others. These programs should be expanded to enhance agroforestry contributions to meeting regional sustainability goals.

Existing programs not readily identified as sources of support for agroforestry should be identified as well. For example, the creation of greenways, shelterbelts and riparian buffers could be realized through state and federal water quality programs and, perhaps, funds available through the Interstate Transportation and Enhancement Act (ISTEA). In addition, land trusts and environmental programs utilizing conservation easements could be used to promote agroforestry.

New programs could be developed as well. For example, the Conservation Reserve Program (CRP) authorized by the 1985 Farm Bill created opportunities for agroforestry practices by removing highly erodible crop lands from intensive agricultural production and placing them under less-intensive uses like permanent grass, legumes, shrubs or trees. While only 7% of the 35.4 million acres enrolled in the CRP were planted to trees, a Missouri study found that up to 30% of CRP landowners were receptive to agroforestry practices, especially if additional funds were available (Licht 1993, Monson et al. 1991).

Conclusions

Agroforestry practices can contribute much to the sustainability of the Intermountain Region's human and natural systems. The region particularly needs to adopt agroforestry practices that create economic opportunities in rural areas, enhance energy efficiency and livability in human environments, and improve and protect water quality and wildlife habitat. These opportunities can be realized through (1) increased research and

technology transfer, (2) improved coordination between agencies, universities and the private sector, (3) increased education and training, and (4) new and expanded agroforestry incentive programs.

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Agroforestry Opportunities in Northern California, Oregon, and Washington[1]

Linda H. Hardesty and Linda M. Lyon[2]

Abstract — The Pacific Northwest offers a dramatic range of landscapes and land uses in which agroforestry may further economic and resource conservation goals. Agroforestry practices common here are forest grazing, windbreaks and shelterbelts, and harvest of special forest products. Windbreaks and shelterbelts are vastly underutilized. Cultivation of hybrid poplar and woody riparian buffer strips hold untapped promise for improving landscape sustainability. Silvopasture and enrichment plantings are not widely known, but may become so in the future.

The greatest potential for realizing the full benefits of agroforestry exist on private land due to landowner's greater decision making flexibility. We see lack of technical assistance and demonstration areas as the greatest obstacles to increasing landowner's use of agroforestry. A number of economic factors will affect the future use of agroforestry. Scarce research *within the region* on use of woody riparian buffer strips is a cause for concern as results extrapolated from other regions may not represent Northwest conditions. Riparian restoration is a priority on public and private lands, therefore, developing this research base is a high priority. Hybrid poplar will probably become increasingly common in agricultural landscapes, and hard data are needed on the environmental influence of these plantations.

Regional Description

The Pacific Northwest is a region of dramatic physical and environmental contrasts, ranging from high alpine environments to moist, lowland rain forests and high desert. Land uses, and opportunities for agroforestry vary accordingly. Proximity to the Pacific Ocean, and elevation are the major climatic influences. A rain shadow lies east of the Cascade, Olympic and Coast ranges while west of the mountains, heavy rainfall and moderate temperatures prevail.

A geologic history including tectonic accretion, intense vulcanism and glaciation has resulted in a complex mosaic of soils (fig. 1). Coniferous forests occupy the moister sites, while shrub-steppe and grassland characterize more arid regions (fig. 2).

The Northwest's human history includes the subsistence activities of early Native Americans, fur trapping, mining and harvest of the massive ancient forests. Agricultural development was less dramatic, but has exceeded all other human activity in its impact on Northwest landscapes. Agriculture was confined by aridity until government water development led to expansion of irrigated agriculture (fig. 3). Livestock production depends upon private base properties and public rangelands.

Forests are still the most extensive land type in the region (tables 1&2). National controversy over old growth forests in the Northwest, and the difficulties of communities still economically and culturally dependent on forestry have come to symbolize how environmental concerns are trans-

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forming American life. Urban development is concentrated along the coast and the Columbia River system. Population growth is creating intense pressure for conversion of the remaining agricultural, forest and rangelands in urbanizing areas. Production agriculture, range livestock production and commercial forestry, once the traditional engines of economic growth, all find themselves in a defensive position.

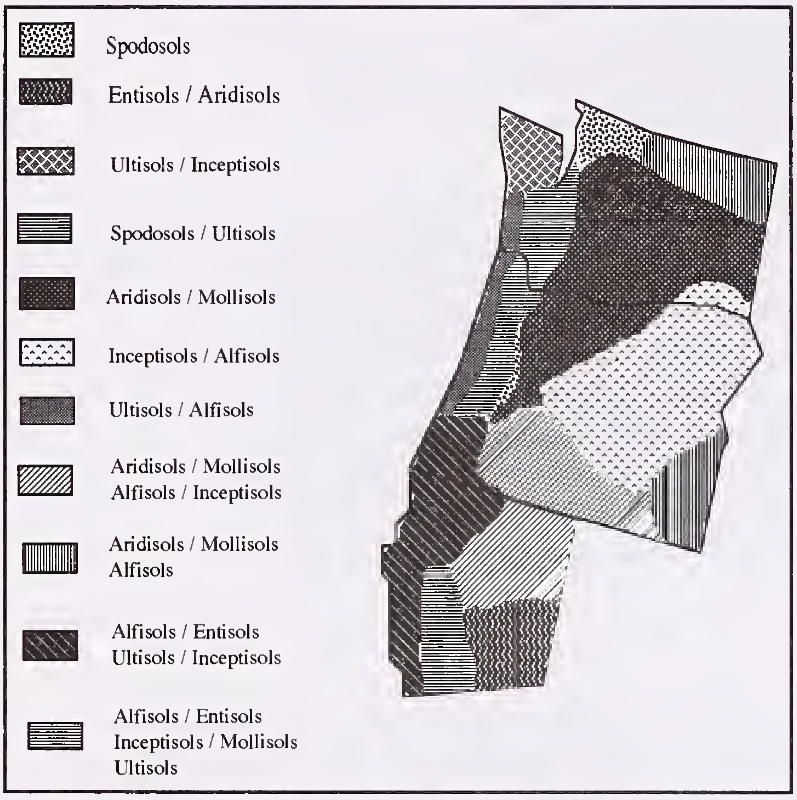

Figure 1 — General distribution of soil great groups in Northern California, Oregon, Washington.

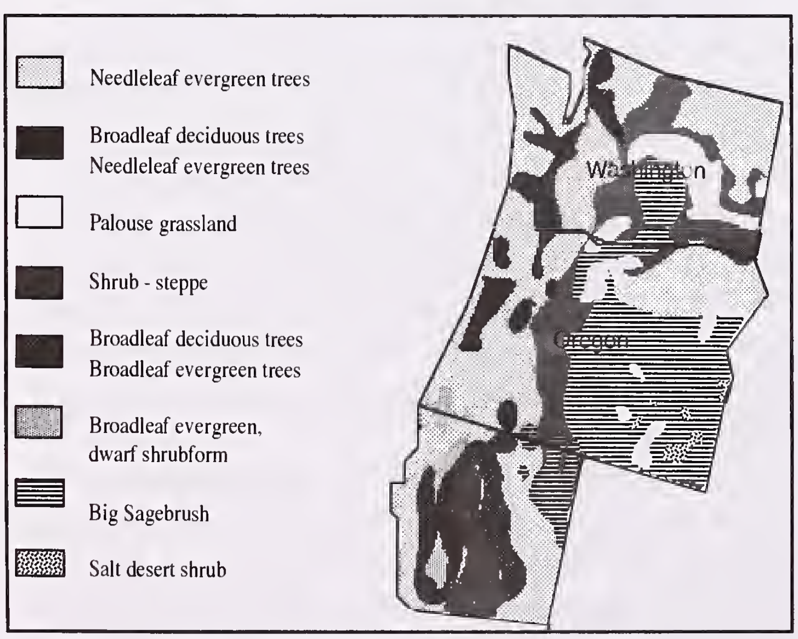

Figure 2 — Major vegetation types of Northern California, Oregon, Washington.

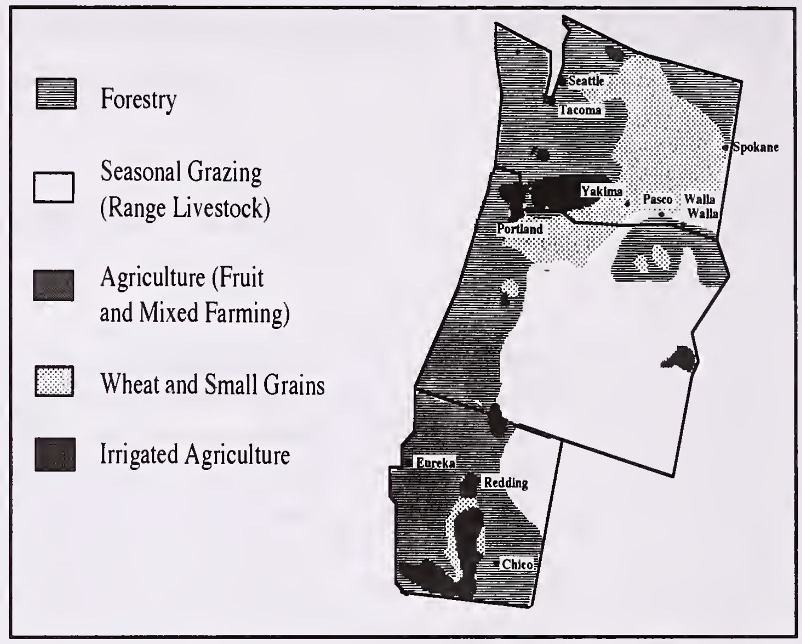

Figure 3 — General land use pattern and population centers in Northern California, Oregon, Washington.

Table 1 — Total land area (1000s acres) by land type, of California, Oregon, Washington and the United States (USDA 1990).

Land type	CA	OR	WA	Regional Total	US Total
Forest [1]	39381	28055	21856	89292	731374
% of state	39	45	51	—	—
% of US	5	4	3	12	32
Range	38487	22031	7522	68040	770353
% of state	39	36	18	—	—
% of US	5	3	1	9	34
Other [2]	21905	11460	13105	46470	755847
% of state.	22	19	31	—	—
% of US	3	1	2	6	34
Total acres	99773	61546	42483	203802	2257578
% of US	4	3	2	—	9

[1]includes forested rangelands
[2]includes crop, pasture, waste and developed areas

Sustainability Issues in the Northwest

Erosivity

As a geologically young and active region, erosion is, to some extent, a natural occurrence in the Northwest although greatly exacerbated by human activity. Numerous federal and state pro-

Table 2 — Non-federal cropland, pasture, rangeland, and forestland by land capability class (USDA 1990).

Land capability class	Cropland				Pasture				Rangeland				Forestland				Total for region
	CA[1]	OR	WA	R	CA	OR	WA	R	CA	OR	WA	R	CA	OR	WA	R	
	Percent[2]																
I	20	4	2	11	5	1	—	2	—	—	—	—	—	—	—	—	3
II	31	28	16	26	11	21	19	17	1	1	—	1	—	1	3	2	7
III	31	46	48	40	35	26	34	31	6	5	12	7	3	4	15	7	16
IV	14	16	27	19	31	23	27	27	18	8	17	15	14	7	26	16	17
V	—	2	11	—	2	5	2	3	—	2	—	—	0	0	—	—	—
VI	2	3	5	3	8	18	16	14	24	30	24	26	37	55	34	41	26
VII	2	1	1	1	7	6	2	5	46	53	45	48	43	32	22	33	29
VIII	8	0	3	—	1	2	—	—	5	—	1	3	3	—	—	1	2
Total acres (1000s)	10,519	4,356	7,794	22,669	1,393	1,966	1,345	4,704	18,126	9,393	5,636	33,155	15,239	11,890	12,689	39,818	100,346

[1]*CA=California, OR=Oregon, WA=Washington, R=Regional total*
[2]*Percents may not total to 100 due to rounding*

grams have targeted agricultural erosion. Advances such as reduced tillage and the Conservation Reserve Program are aimed at reducing agricultural erosion, yet Washington was among only 10 states nationwide to show an increase in average wind erosion (3.7 to 5.2 tons/acre) between 1982 and 1992 (Associated Press 1994). During this same period, both Oregon and Washington have seen decreases in average water erosion, to 3.9 and 5.1 tons/acre, respectively, while the national average dropped to 3.1 (Associated Press 1994).

Accelerated erosion on rangelands has been attributed to overstocking, however improper timing of grazing and animal distribution also disturb soil. Recently, attention has been focused on rangeland riparian areas where abuses of the uplands become cumulative when combined with improper riparian management. Riparian zones that traverse well-managed uplands generally maintain their natural functions.

Old growth issues have obscured the fact that most Northwest forests are second growth or younger, on drier sites with multiple uses including grazing, mineral development, recreation and water production. Roading has been a major source of erosion on forest lands, that while attributed to timber harvesting, also serves other uses. Recreation, particularly horse packing, 4-wheeling and mountain biking, adds to erosion problems. Fire suppression and harvest practices have resulted in large tracts of dense, even aged forests with a simplified species composition that are vulnerable to catastrophic insect and disease outbreaks (Everett et al. 1993). It will take decades to restore the health of many of the region's forests. In the interim, the threat of catastrophic fire with associated erosion and sedimentation, is significant.

Non-Point Source Water Pollution

A major consequence of erosion is pollution of surface waters with sediment, excess nutrients, chemicals and pathogens. An additional source of pollutants is improper use of agricultural and household chemicals and septic problems on rural/suburban acreages. In an Illinois watershed where urban area accounted for only 5% of the land and cropland 90%, urbanization was the controlling factor in nitrogen and phosphorus loading (Osborne and Wiley 1988). Neglecting household inputs could be a serious mistake.

Riparian Degradation

Due to extreme hydrologic regimes, riparian areas in most of the Northwest are inherently unstable. Human activity has further destabilized many, causing increased flood hazard, excessive erosion, and loss of vegetation that physically

binds the riparian zone together. Loss of vegetation increases the force of flowing water, compounding bank cutting and scouring, and eventually lowering the water table. Loss of overstory vegetation can result in increased water temperatures that are lethal to salmonid fish and impoverishes the habitat of other riparian wildlife.

Fish and Wildlife Habitat Needs

Wildlife are a major concern in managing agricultural, forest and range lands and associated waters, particularly when wildlife utilize different types of habitat during different seasons or stages of the life cycle. For example, anadromous fish spawn in streams hundreds of miles inland from the ocean where they grow to maturity. Land uses anywhere in the watersheds they use can affect survival and reproductive success. Loss of forested habitats may affect declining neotropical migrant bird populations. Deer and elk that summer in the mountains are finding their winter ranges increasingly disturbed by agricultural, residential and industrial development.

Public Land Issues

Overall, 32.1% of the United States is federally owned, but Washington, Oregon, and California include 28.4, 48.9, and 47.4% federal land respectively (USDI 1983) (fig. 4). At statehood, federal lands were offered as an incentive to settlement, development and economic growth. This view did not shift when, following World War II, other non-consumptive uses of the federal lands increased. The Multiple Use Sustained Yield Act of 1964, and the Federal Land Policy and Management Act in 1976, reflected a view that all uses could be accommodated. Now, it is clear that "the public" is actually many publics with conflicting views of the federal lands.

Private landowners whose land values, access to traditional uses, and markets are affected by public lands are struggling as changes in public land management affect their lives and livelihoods. An example is the reduced federal timber harvest in Washington and Oregon resulting from injunctions against harvesting on National Forests in northern spotted owl (*Strix occidentalis caurina*) habitat. Stumpage prices skyrocketed and many non-industrial private forest land owners responded. This has resulted in significant loss of farm woodlots, roadside trees and private timber stock, accelerated erosion and weed invasions. Some fear that changes in public lands grazing will put unacceptable pressure on private grazing lands, often riparian or lowland sites particularly vulnerable to mismanagement. These are only two examples of the numerous relationships between private and public land management.

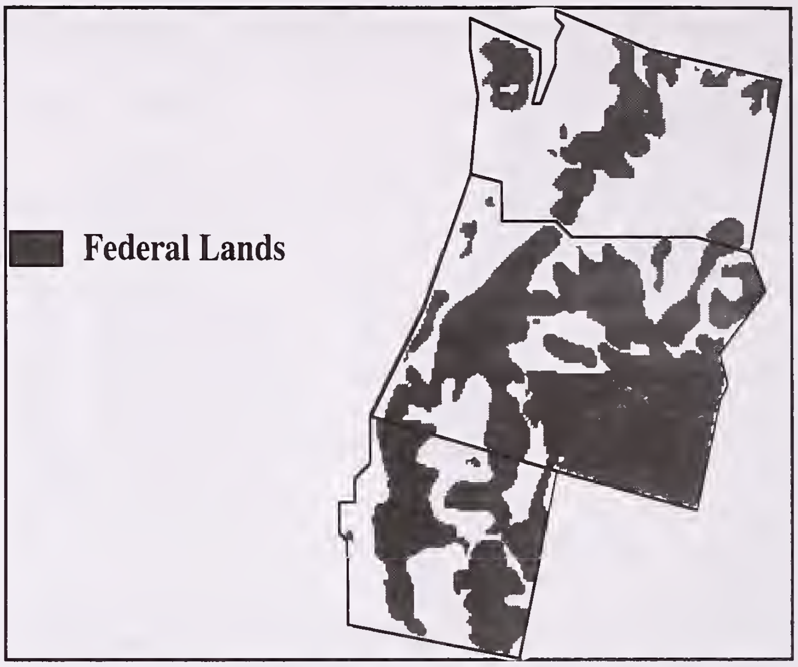

Figure 4 — Distribution of federal lands in Northern California, Oregon, Washington.

Quality of Life and Economic Health

The quality of life in the Pacific Northwest is its greatest attraction: a clean, healthy place with a variety of outdoor recreation opportunities. The region has a promising economic future based on high tech industries, services and other "clean" enterprises, coupled with an abundant natural resource base and favorable access to the Pacific Rim. Reaching this promising future has been more difficult than some anticipated. Many rural economies are devastated by the collapse of extractive industries or agricultural changes.

Educational opportunities and social services lag behind many regions. The cost of providing even basic services often overwhelms communities with a small tax base. Further, payments in lieu of taxes have declined with revenue generating activities on public lands. The region is in a stressful period of economic and cultural transition.

The Current Contribution of Agroforestry

Forest Grazing

Forest grazing occurs primarily in ponderosa pine and Douglas-fir forests that provide forage early in the rotation (transitory range). No reliable data exist on acreages of transitory range due to its temporary nature. Until recently, most forest grazing has been an opportunistic activity. In the 1980s, restrictions on using herbicides on federal forest lands led foresters to look more closely at livestock to manage unwanted vegetation on plantations and improve tree growth (Doescher et al. 1987, Halloin 1990).

It is more difficult to run livestock profitably on forest range than on non-forested range (Hardesty et al 1993), and there is a trend toward livestock producers being paid to graze livestock on plantations. In California, producers are paid to graze their stock on firebreaks. Future prospects for forest grazing are not at all clear. Proposed reductions in allowable cut on federal forests, increasing fuel costs associated with transport and management of livestock, the current anti-grazing sentiment, and relatively low cattle prices are all factors that may reduce the prevalence of forest grazing in spite of its silvicultural advantages.

Silvopasture

Silvopasture refers to a timber-pasture production system in which both overstory and understory species are selected and managed for production. Studies in western Oregon (Sharrow 1991, Sharrow and Emmingham 1991, Sharrow et al. 1992, and Carlson et al. 1994) demonstrated that it is possible to produce forage and livestock without reducing growth of the tree crop. Silvopasture is rare in the Northwest, but has excellent prospects. Increasing profitability of high quality logs, coupled with anticipated restructuring in the region's range, pasture and forage markets suggest that silvopasture can satisfy two markets while maintaining an attractive environment in urbanizing rural areas.

Windbreaks and Shelterbelts

Kort (1988) summarizes the benefits of windbreaks for crops: "increased yields due to reduced wind erosion, improved microclimate, snow retention and reduced crop damage by high winds." Northwest crops that are responsive to shelter are winter wheat, barley, alfalfa and grass hay, orchard crops and vineyards. Marginal or drought prone areas benefit the most.

Windbreaks are used to protect livestock from wind, blowing snow and dust, reducing environmental stress and feed requirements (Hintz 1983). Hintz reports that beef cattle require additional feed when temperatures drop to 59° F wet or in a summer coat, or 18° F in a heavy winter coat. Even without wind-chill, such conditions occur throughout the year in the Northwest. Shelterbelts are most often used for feedlots, wintering pastures or lambing and calving grounds.

Wildlife use of shelterbelts varies from thermal, escape or refuge cover, to sources of food, reproductive sites or travel corridors (Johnson and Beck 1988). Species composition and structural characteristics of the shelterbelt influence its habitat characteristics. Wildlife deriving substantial benefits from shelterbelts include ring-necked pheasants (*Phasianus colchius*), mourning dove (*Zenaida macroura*) great horned owls (*Bubo virginianus*), and kingbirds (*Tyrannus* spp.)(Johnson and Beck 1988). No generally recognized bird or mammal "pest" species derive substantial benefits from shelterbelts.

As rural homesteads increase in number, the desire for privacy, aesthetic improvement, noise

abatement, and improved wildlife habitat, as well as energy conservation, may encourage more landowners to plant shelterbelts. Windbreaks and shelterbelts are underutilized for a range of environmental problems, yet many of the windbreaks established in this region during the 1930s have been removed or have deteriorated from age or lack of care. Windbreaks use valuable land, limit the use of aerial chemical application, and can be expensive and complex to design and establish. Concerns about viewsheds limits use of windbreaks in some cases. Pressure to reduce the use of agricultural chemicals suggest that aerial application will be less of an obstacle in the future. Public interest in wildlife may be an avenue for expanding use of shelterbelts to accomplish other less popularly recognized benefits such as soil conservation.

Special Forest Products

Special forest products are naturally occurring non-timber resources that are harvested for commercial or individual use. Gathering special forest products is economically and socially important in the Northwest. In most cases, no economic means of intensive cultivation exists, but using agroforestry principles, foresters can develop harvestable populations of some products.

In 1989, the floral greens and Christmas ornamental market generated an estimated $128.5 million in product sales in western Oregon, Washington and southwestern British Columbia (Schlosser et al. 1991). Sword fern (*Polystichum munitum*), beargrass (*Xerophyllum tenax*) and Evergreen huckleberry (*Vaccinium ovatum*) are among the species that respond to management during early to mid-seral stages of stand development (Schlosser et al. 1992).

Wild mushroom harvesting by both commercial and recreational pickers has grown tremendously in recent years. Schlosser and Blatner (1994) estimate that in 1992, this industry contributed over $41.1 million to the economy of Idaho, Oregon and Washington. Forest management for mushroom production is just being explored in the Northwest. Many species stop fruiting after clearcutting, while some are stimulated by cutting and burning (Molina et al. 1993). A generally recognized need is to better manage picking to reduce local conflicts, manage liability and insure adequate remuneration to landowners.

The recent interest in the bark of Pacific yew (*Taxus brevifolia*) to treat cancer is one example of the potential value of medicinal products from Northwest forests. Managing forest land for huckleberries and bee pasture is also traditional in some areas. We expect to see increasing emphasis on management for special forest products on forest land of all ownerships.

Enrichment Plantings

Enrichment plantings are woody plants in configurations that do not constitute a woodlot or windbreak, but yield benefits such as shade, forage, wildlife habitat or a product (e.g. nuts or ornamental materials). Enrichment plantings offer environmental benefits on almost any parcel of land in the Northwest and offer economic benefits on many. Given the minimal investment required relative to the cumulative benefits which may accrue, such practices should be promoted on private and public land. This is an opportunity for landowners to learn about and express an interest in resource stewardship. Programs offered by the National Arbor Day Foundation, nurseries, conservation or educational groups are all means of encouraging such activities, with potentially enormous cumulative benefits. An example is the California group Treepeople, that has capitalized on the interests of a range of groups and individuals to accomplish tree planting and associated resource management activities.

Riparian Plantings

Riparian restoration, including protection and improvement of water quality and aquatic habitat, is one of the most urgent land management issues in the region. Woody plants were original components of most Northwest riparian zones.

Much of this overstory has been lost and restoration is a priority.

Johnson and Ryba (1992) review the literature on riparian buffer strip widths. For western Washington they suggest buffers of 15-30 m to provide minimal maintenance of riparian function, while buffers of greater than 30 m are adequate for most functions. Castelle et al. (1992) and Osborne and Kovacic (1993) point out that the variety of needs: nutrient or sediment capture, bank stabilization or wildlife habitat management; and biophysical conditions, dictate against standard buffer strip widths. Petersen et al. (1992) advise that riparian tree plantings be at least 5 trees wide to avoid exposing small birds to increased raptor predation, while nutrient retention increases with increasing width up to 10m.

The relative advantages of forest versus grass buffers for nutrient capture is unclear (Osborne and Kovacic 1993). There may be advantages to multistory buffer strips. Buffers can become nutrient saturated and lose their effectiveness (Osborne and Kovacic 1993). Harvesting, or other means of maintaining an early successional, nutrient storing state might increase long-term effectiveness.

Of all agroforestry practices, woody riparian buffers is the one with the greatest future importance due to the extraordinary economic and environmental costs of not improving the region's watersheds (table 3). Unfortunately, we have a very sparse research base from which to develop and recommend suitable practices. Most experimental evidence to support recommendations for riparian plantings are from other regions. The unique qualities of the Northwest require that caution be used in extrapolating from differing ecosystems.

Table 3 — Lineal miles of riparian zones with varying degrees of cover, by width (Garrett et al. In Press).

Cover type and width		CA	OR	WA	Total
Without trees or shrubs					
	<100 ft.	39847	10395	15708	65950
	100-500	3237	1095	720	5052
	>500 ft.	2552	102	24	2678
Total		45636	11592	16452	73680
With shrubs					
	<100 ft.	9636	1650	2838	14124
	100-500	371	330	459	1160
	>500 ft.	84	39	18	141
Total		10091	2019	3315	15425

Orchard and Christmas Tree Interplanting and Grazing

Much of the understory space is not fully occupied in the early years of orchard and Christmas tree plantations. Intercropping and grazing are both atypical, but grazing is more common. Most orchards use herbicides and mowing to manage the understory, yet orchards can produce substantial quantities of high quality forage (Hardesty, unpublished data) and a favorable environment for animals. Technical guidelines are being developed for orchard grazing (Hardesty 1991, Hardesty and Howell 1991, 1992, 1993) but none are known for Christmas tree plantations. A downturn in the fresh Christmas tree market and increasing use of high density planting patterns in orchards suggest these practices are not likely to become widely used. However, the opportunity exists to improve farm efficiency and realize environmental benefits with these practices.

Hybrid Poplar Plantations

Hybrid poplar is a relatively new crop in the Northwest (Heilman et al. in press). Poplar is in demand for lumber, fuelwood and energy, and pulp chips. Although a monoculture of hybrid poplar is not agroforestry, when integrated into a farm or landscape where it provides benefits to adjacent lands, an agroforestry system exists.

Hybrid poplar culture may offer environmental benefits, although these are mostly speculative to date. When planted in a coppice system replacing annual crops, tillage is reduced, as are chemical and fossil fuel inputs. There are implications for improved soil stability, soil structure and infiltration, and reduced non-point source pollution. Wildlife may also benefit.

Current trends suggest there will be tremen-

dous expansion of hybrid poplar plantations over the next few years. In 1983, Oregon, Washington, California and British Columbia had only 40 acres of hybrid poplar plantations. Today, there are approximately 18,000, and projections are that 70,000 acres will be in hybrid poplar within 5 years (Heilman, pers. comm.).

Realizing Agroforestry's Potential in the Northwest

Because the benefits of agroforestry range from kilograms per hectare of biomass, to intangibles such as improving the quality of life, aggregating its potential is impossible. Further, a number of factors will determine how fully this potential can be achieved.

Economic Issues

Economics influence the use of agroforestry. Developing a market for agroforestry products is often neglected, particularly when a new product is involved: a farmer who plants hybrid poplar for chips, or forest land owner who buys sheep to manage understory vegetation. Cost of establishment, and lack of financing are documented concerns among prospective agroforesters (Lawrence and Hardesty 1992, Lawrence et al. 1992). Agroforesters in Washington saw cost of establishment as less of an obstacle than landowners who were not agroforesters, suggesting that costs may be less than anticipated (Lawrence et al. 1992). Real data on costs and returns are needed to be market agroforestry successfully.

External cost savings from agroforestry may be underestimated: reducing erosion from croplands saves future yield losses, less sediment means municipal water treatment and downstream dredging costs are reduced. The difficulty is identifying these savings and allocating them between those who incur the cost and those who realize the savings. Often individuals save by passing costs (e.g. sediment generation) to the public, or to future land managers as a consequence of prevailing economic models that exclude external costs. Revised models such as "green accounting" and conservation compliance should make agroforestry more economically attractive

Neither private forest land owners nor technical assistance providers feel that adequate technical assistance is available for agroforestry (Lawrence and Hardesty 1992, Lawrence et al. 1992). We believe this is because the relevant research base is weak and demonstration sites are lacking. Few technical assistance personnel have enough knowledge or experience with agroforestry to provide assistance, which contributes to agroforestry having low or unclear priority among existing program responsibilities. When no direct commercial interest is involved, private research and development funding is scarce. Government funds are stretched by multiple demands, and agroforestry, having no well organized beneficiary group, does not fare well in competition for research funds to meet existing or future information needs.

Planning Issues

The objectives of an agroforestry practice must be explicit as the practice is designed, implemented and evaluated. This appears obvious but often it is only after that fact, as the "reason" for failure, that all expectations become explicit. The limits of our knowledge must be recognized, and the potential benefits not be oversold, if agroforestry is to be more widely accepted.

With the exception of forest grazing, special forest products and riparian buffer strips, most of the practices we describe are best suited to private lands. Private lands are often more productive and more accessible, and the private land manager currently has considerably more flexibility than the public land manager.

Problems such as improving water quality, preserving biodiversity, and creating long-term economic security, are less discreet in their boundaries than is the thinking of those who seek to solve them. Complex problems cannot be solved by simply changing the management of individual parcels of land, using the knowledge of a sin-

gle discipline. The goals of ecosystem management: treating landscapes as functionally integrated systems using many types of knowledge, are admirable, but will be difficult to implement. In the interim, we must strive for incremental improvements, that will, in aggregate, improve the sustainability of Northwest ecosystems. We must act now on the small scale and short-term, while learning to think, plan and act on broader geographic and temporal scales.

More opportunities exist to improve land management than there are human or financial resources. Land managers must practice triage: investing in those lands and practices that will maintain the most future options, that will realize the greatest improvement for the resources invested, and that will act as a keystone holding together functioning ecosystems.

Priorities for Advancing Agroforestry in the Northwest

Priorities for realizing the full potential of agroforestry in the Northwest include better coordination among multiple contact points for technical assistance, training for technical assistance personnel, clarifying the financial assistance options for agroforesters, and improving the research base.

Research priorities include developing regional and site specific research and demonstrations of the ecological and economic performance of various agroforestry practices. The benefits of riparian planting and effective planting strategies need to be developed and verified. The long-term impacts of forest grazing and harvesting of special forest products should be assessed. Cultural practices for sustainable production of special forest products need to be developed. Constraints to use of windbreaks need to be identified so that their use might be expanded. Programs for promoting enrichment plantings need to be developed. Benefits to wildlife may be particularly persuasive benefits of both windbreaks and enrichment plantings if such benefits are documented. Hard data are also needed on the environmental influence of hybrid poplar plantations. Agroforestry practices not currently used in the region: living snow fences and alley cropping, may also merit investigation.

Agroforestry is vastly under-exploited for both production and protection of resources in the Pacific Northwest. Establishment costs must be weighed against the cost of not exploiting the protective functions of well designed tree plantings, particularly in the context of riparian function and soil erosion. Although the research base for many agroforestry practices is weak, existing information is not being fully utilized to promote wider use of agroforestry. While the potential of agroforestry varies on public and private lands, we suggest that with expanded effort to develop agroforestry, we can expect to see significant progress towards resolving many natural resource problems in the Northwest.

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Role of Agroforestry in Sustainable Land-Use Systems[1]

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Abstract — Agroforestry is not a new concept; it represents an array of land use systems that have both production and environmental protection benefits, which fit nicely with the concepts of conservation developed more than half a century ago. The characteristics of agroforestry practices that enable these benefits to be realized are discussed in this paper. In relating agroforestry to sustainability, we must define "what" is to be sustained and "for whom." In some instances, the introduction of trees into agricultural systems may not be desirable. Furthermore, we may not always want to sustain certain land-use systems. Where agroforestry is desirable, benefits include a built-in flexibility to deal with uncertainty in the context of land use changes, a resiliency that exceeds that of other land-use systems, and several attributes that complement the objectives of conservation and watershed management.

Introduction

Agroforestry involves several different land-use systems and practices. Definitions and characteristics of agroforestry systems have been described extensively (Raintree 1987, Nair 1989, 1990, 1993) and will not be repeated here. Nair (1993) discusses many of these in terms of the diversity of products and amenities that can be produced. Although not often explicitly defined, agroforestry practices are considered to have attributes that promote sustainability more than other production-oriented approaches to land management. This paper examines the linkages between agroforestry and sustainability in land use. Before getting into the main discussion, we need to make five initial points.

1. *The concepts of "sustainable development" and "sustainable land use systems" are not new.* Gifford Pinchot, President T. Roosevelt, and the others who developed the early conservation movement had sustainable land-use practices in mind and, in fact, discussed the characteristics of such systems in detail. However, there are some lessons from the past that remain to be learned. There still is a lack of widespread blending of the production and environment centered views of people, which leads to the second point.
2. *The use of agroforestry technologies in sustainable land-use practices involves both production and protection of the natural resources base on which production depends.* Many people today focus primarily on protecting and sustaining the physical/biological environment, forgetting the production part of conservation and the development part of sustainable development. Others focus only on production needs within the context of economic growth. They forget or ignore the importance and indeed necessity of protecting the natural resource base on which future generations will depend for their production. Agroforestry in its broadest sense is the blending of production with protection; and thus it fits in nicely with the concepts of conservation.
3. *The use of trees in land-use practices is not always*

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positive in terms of sustainability and results are not always positive. If trees are not introduced into land-use practices in an appropriate manner, they can reduce productivity and the sustainability of land-use systems by competing for space, light, nutrients, and water with other, more highly valued crops. Lal (1991) points out that some of the benefits that often are promoted, such as the recycling of nutrients by deep rooted woody plants and nitrogen fixation by certain trees, neglect other, negative effects. In some instances, the competition for soil moisture and nutrients between woody perennials and crops can have detrimental effects on crop and overall productivity. Also, some woody plants have allelopathic effects while others serve as host plants for pests that can adversely affect crops.

If there were no negative impacts from using trees in land-use practices, then there would be little need for research on the subject, nor would there be much need for conferences such as the present one. Further emphasizing this point, we cannot take for granted that trees and agroforestry systems are compatible with sustained improvements in production from the land. Careful study is needed to find those combinations of trees and other land uses that maximize the overall, sustainable production from a given land area. In some cases, it might mean no trees; in other cases, it might mean total forest cover. In between are agroforestry systems, involving the introduction of trees into agricultural or livestock systems. Therefore, we are searching for the most positive ways in which trees can be introduced to support sustainable land use, both in a biological context and in a socioeconomic context.

4. *Since we cannot really know whether a land use is sustainable far into the future, the best operational means to deal with sustainability is to avoid practices that are clearly unsustainable.* Although concepts of sustainability have been presented elsewhere (Brown et al. 1987, Conway 1985, Gregersen and Lundgren 1990), putting these concepts into practice remains somewhat illusive. Conceptually, we can define sustain ability, but when we examine land-use practices that are actually being implemented, it is not clear how to judge whether a practice is truly sustainable or not. On the other hand, certain indicators, such as excessive soil erosion, water pollution, and declining crop productivity, suggest that land-use practices are not sustainable. Thus, in addressing this issue, one approach is to determine what agroforestry can do to help avoid unsustainable land uses.
5. *Aiming for sustainability of the productive use of land is different from aiming for sustainability of a particular land-use practice.* We always want to achieve the former, but only sometimes will we want to achieve the latter. This point relates to the dynamics of land uses and the changes that take place in what humans want from the land. A given land-use practice can come and go; it may or may not return some time in the future. What matters is not sustaining a particular land-use practice, but to sustain the benefits and, importantly, the productive capacity of the underlying soil and associated resources.

Sustainable Land Use

Any discussion of sustainable land use must first decide "what" is to be sustained, and "for whom" is it to be sustained. Terms such as "production agroforestry" and "environmental agroforestry" place emphasis on what is to be sustained, even though these terms are general and somewhat vague. To some extent, these terms also imply the "for whom", since individual farmers more often are in the business of sustaining productivity, while other parts of society may focus on the environmental benefits. Agroforestry should by design provide both environmental and productivity benefits; in fact, they cannot produce one without the other in almost all instances.

Sustainable land use could be considered as that which results in production of goods and ser-

vices for the present generation without causing a decline in welfare of future generations. This definition complements that of watershed management, which is "the process of organizing and guiding land and other resource use on a watershed to provide desired goods and services without affecting adversely soil and water resources" (Brooks et al. 1991).

Sustainable development and sustainable land use remain as concepts that are used in many different ways by different people, depending on their purposes. Here, we wish to stress three dimensions or aspects of sustainability that are important when looking at agroforestry's role in questionable land use. These are:

1. Building in flexibility to deal with uncertainty and the dynamics of changing needs and wants.
2. Improving the resiliency of a land use.
3. Creating positive externalities and linkages among land-use practices and their impacts.

How do each of the above relate to agroforestry? How can agroforestry help to achieve the conditions implied by these concepts? The remainder of the paper addresses these questions.

Building in Flexibility to Deal with Uncertainty

The only thing we know for sure about the future is that it is not predictable — there are many uncertainties. We cannot say that any particular land-use practice is sustainable, but by building in flexibility we can better cope with uncertainty and thereby help avoid unsustainable land use.

Agroforestry systems and practices by design are diverse. This diversity is the result of more efficient utilization of moisture, space, nutrients, and energy on a given area of land. The multiple products and amenities that can potentially be produced from agroforestry practices (figure 1) translates into the flexibility needed for the landowner or resource manager to cope with the unknown future.

Whether indigenous or introduced woody perennials are components of a practice, there often are several products from the trees themselves, such as poles, fuelwood, forage, nuts, and fruit that can be consumed directly by farmers, or in some cases, sold in the market place. As combined production systems, agroforestry practices have the potential to help farmers deal more effectively with changing markets and may in fact

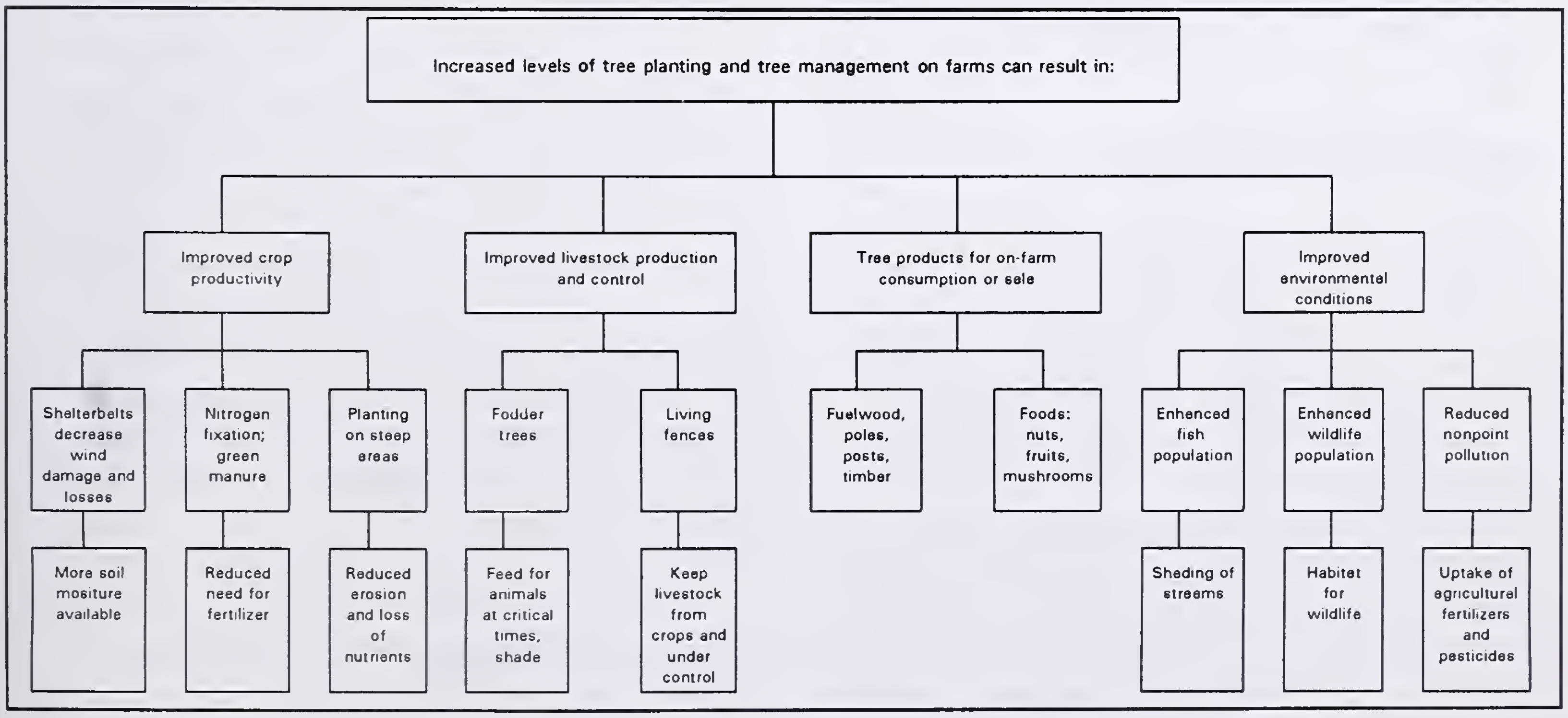

Figure 1 — Multiple products and amenities potentially produced from agroforestry practices (adapted from Gregersen 1988).

help to develop new markets. The financial benefits to farmers can thereby be enhanced.

More subtle benefits to farmers can, in some instances, be achieved because of reduced requirements for inputs of fertilizers and perhaps pesticides. For example, while not unique to agroforestry, nitrogen-fixing plants (trees in the case of agroforestry) have the potential to reduce fertilizer costs while improving production. Reduced use of chemicals has environmental benefits that relate to the externalities that are discussed later in this paper.

The amenities derived from agroforestry also can have benefits such as providing wildlife habitat, protecting fisheries through riparian management, and providing for an aesthetically more pleasing environment (for example, greenbelts in dryland areas). Although such benefits are not usually considered in the same light as goods that are sold in the marketplace, some can have economic value. For example, enhancement of wildlife habitat can provide additional income for farmers in the way of user fees.

The diversity of crops and products helps farmers and resource managers avoid risks associated with monocropping. Single crops are more susceptible to pests, diseases, and the occurrence of droughts, frost, and hailstorms than most agroforestry systems. The flexibility provided to landowners under such conditions relates closely to the resiliency of agroforestry systems.

Developing Resiliency

Commonly, land-use practices have been developed and have become finely honed to average or ideal environmental conditions in an area. However, when droughts or frosts occur, that year's crop can be partly or totally destroyed. The great drought of mid-America in the 1930s is an extreme example.

Most agroforestry technologies can either moderate the effects of such phenomena or, more importantly, can provide resiliency to land-use practices and the farmers who depend on the land, so they can more rapidly bounce back after such phenomena. Examples of how agroforestry can provide this resiliency are:

- Windbreaks helping sustain crops by conserving soil moisture during windy dry periods that would otherwise destroy crops in a monocropping system.
- Tree fodder being available as a substitute for hay and native forage during extended periods of drought.
- Tree products providing a source of income for farmers during periods of drought or following hailstorms when annual crops have been destroyed.
- By combining woody perennials with forage and food crops, production can be carried out on areas that are too fragile for intensive, monocropping systems.

Agroforestry practices are structurally and functionally more complex and, because of this, they naturally are more resilient than other types of land use. Although some components within a given agroforestry practice can be affected by occurrences of drought, frost, or hailstorms, for example, other components may be less affected or unaffected. The unaffected components in the system can thus continue to provide products and protection benefits.

Linkages With Other Land Uses and Externalities

Agroforestry technologies often can be used to develop positive complementarities among land - uses on a particular site and land uses off - site, or downstream. Such benefits can be considered as coinciding with the objectives of watershed management as discussed in Brooks et al. (1991). Using a watershed management framework (Gregersen et al. 1987), the benefits (economic and others) of agroforestry in both uplands (upstream) and downstream areas can be considered in terms of:

Benefits to Uplands

- Soil protection and reduced erosion by water and wind can result in increased production

(reduced losses) over time; soil conservation is a fundamental requirement of all agroforestry systems.
- Fixation of atmospheric nitrogen by some tree species can add nitrogen to the soil which, in turn, can improve crop production.
- By combining trees and other woody perennials with forage and food crops, some of the hydrologic benefits associated with forests can be achieved. Although individual trees do not necessarily function as forests, they can have the following effects: 1) Improve infiltration of rainfall and reduce sur face runoff; in some instances, the frequency and magnitude of localized flooding can be reduced; 2) Provide buffers between cropping systems and aquatic systems, with the potential to enhance and protect aquatic ecosystems and improve the quality of streamflow by reducing sediment and nutrient loading; and 3) Alter the pattern and amount of soil moisture to the benefit of other plants or for hydrologic benefits.
- Enhancement of the variety and amount of wildlife by providing more varied habitats can be considered as both a production and environmental benefit. Both game and nongame species can be enhanced. Some complementarities can be important for rural populations from the standpoint of an improved living environment and the increased numbers of wildlife for viewing and hunting.

Off-Site and Downstream Benefits

- The introduction of trees can result in reduced amounts of runoff and water yield from an area; this can have both positive and negative effects downstream.
- Soil stabilization by agroforestry practices that reduces soil erosion can help stabilize stream banks and also can reduce the amount of sediment that is delivered to downstream channels, lakes, and reservoirs. Such benefits can be considered both as economic and environmental.
- Surface and groundwater quality can be improved for "off-site" users. The potential for uptake nutrients and pesticides by trees that would otherwise enter streams, lakes, or groundwater systems is a function gaining widespread attention (Henderson et al. 1991, Schultz et al. 1989, 1991).

Although the above stresses the benefits of agroforestry, the mere introduction of trees into cropping systems does not necessarily have positive effects. In such instances, we would not be interested in sustaining such practices. In fact, when negative effects occur, by definition, these practices would not be sustainable.

Avoiding Unsustainable Land-Use Practices

To this point, we have concentrated on the features of land-use practices that lend themselves toward sustainability, and indicated how agroforestry practices can encompass these features. To move from concepts and general ideas to specific recommendations for implementation is the challenge. We could not possibly make such a transition here—there are too many options and combinations of agroforestry practices yet to be investigated. So what can we say at this point? Returning to a point made earlier, it is difficult, if not impossible, to directly determine whether a particular agroforestry practice is sustainable. What we can do, however, is identify those practices that are <u>not</u> sustainable—and the conditions under which certain practices have been shown to be unsustainable—and avoid them! This approach is one of common sense.

Examples of unsustainable land-use practices are numerous. Here, we will consider two such examples that relate to agroforestry. Wiersum (1984) showed that to achieve water erosion control benefits when trees are grown along with crop plants, it is important to maintain good soil surface protection against raindrops falling from tall tree canopies. To some extent, tree canopies can collect and redistribute rainfall. This process actually can result in the coalescence of small rain

drops into larger drops — which can have a greater erosive power than the original drops. If the soil surface is not protected against such throughfall (by means of maintaining either intermediate height plants or good ground cover on the soil surface), soil erosion can be accelerated. Therefore, under some circumstances, the planting of trees along with crops may not reduce surface soil erosion, but have the potential to increase soil erosion. This situation can be avoided by maintaining vegetative cover at or near the soil surface under tree canopies, and thus, minimizing exposed mineral soil and reducing the impact of falling raindrops.

Coe (1994) discussed the problem of transferring research results of a successful agroforestry practice, in this case, alley-cropping, from one location to another location where it may not be sustainable. Positive results in one location do not necessarily translate into positive results elsewhere. For example, positive results from alley cropping research in humid areas do not necessarily appear under semi-arid conditions; the reason for this can be readily understood—trees compete with crops for light, nutrients, and moisture. Where soil moisture is limiting, the competition for soil moisture can be detrimental to crops.

As a complement to the approach of "avoiding unsustainable practices," we can continue to compile results of long-term experiences with agroforestry and document the biophysical and socioeconomic conditions under which they have been sustained. Before any land-use practice can be considered sustainable, it must be compatible with the biophysical environment, must provide goods and services that people desire, and must be socially acceptable. Improved research in agroforestry, as discussed by Coe (1994), is a key to better understanding various agroforestry practices and where, when, and how they can be successfully implemented. Better designed experiments with appropriate controls will help move in this direction. The socioeconomic dimensions can be better understood by monitoring the implementation of practices over time and in the appropriate biophysical settings.

Conclusions

- Appropriate agroforestry practices provide many of the characteristics of land-use systems that we associate with sustainability. The diversity of agroforestry practices inherently makes them resilient and provides farmers with greater flexibility in coping with uncertainties of drought, frost, pests, and other phenomena that can lead to production failure.
- Agroforestry has the potential to enhance the financial situation of farmers while providing for amenities and environmental benefits to society that we associate with sound conservation and watershed management. The use of agroforestry practices to reduce nonpoint pollution from monocropping areas, by using buffer strips of woody vegetation and integrating trees into cropping systems, appears to have excellent potential and should continue to be researched.
- Agroforestry is not a panacea for sustainable land use; although the potential for enhanced land use exists, there can be detrimental effects. Monitoring of existing agroforestry practices and research must continue so that we can avoid unsustainable practices and promote appropriate technologies.

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Agroforestry-Enhanced Biodiversity: The Good, The Bad, and The Unknown[1]

Michele Schoeneberger, Mary Ellen Dix, and Michael Dosskey[2]

Abstract — Agroforestry, the intentional addition or management of woody plants in agricultural landscapes, can potentially create more stable systems by increasing biodiversity. Two factors must be considered if agroforestry is to be a viable strategy in promoting agroecosystem biodiversity and sustainability. First, agroforestry plantings will impact the biodiversity of the ecosystem regardless of intent in both known and unknown ways that can be beneficial or detrimental to the integrity of the ecosystem. Foreknowledge of agroforestry-induced ecological interactions within the landscape is vital for prudent land management. Second, the cost incurred to establish these plantings must somehow be equitably shared by all who benefit from them. This may be either through returns to the landowner from the services afforded by the planting (i.e. increased crop yields, game species, wood products, or biological control) and/or by cost-share programs that enable the cost to be borne by all who benefit from a more biologically diverse and sustainable agroecosystem.

Introduction

"Biodiversity and agriculture are uneasy bedfellows."
Holloway 1991

Biodiversity refers to the variety and complexity of genes, structures and functions within ecological systems. According to ecological theory, biodiversity imparts resiliency, stability and sustainability to ecosystems. The pursuit of attaining local to global sustainable development in the agricultural arena has brought "biodiversity" to the forefront of policy-makers and ecologists, alike. Unfortunately, biodiversity is a concept more readily accepted and embraced in programs than understood or measured; and whose benefits are more often postulated than proven. This is particularly true when applied in intensely managed ecosystems, like agroecosystems.

Conceptually, biodiversity is broken down into three levels: genetic, species, and community or ecosystem. Each level is comprised of three components: compositional, structural and functional (Table 1). Compositional diversity refers to the number of parts or elements in a system such as species. Structural diversity refers to how the elements of diversity are arranged relative to each other (e.g. size, shape and distribution of species and their habitats). Functional diversity refers to the number of ecological processes within a system, for example, herbivory at the species level and nutrient cycling at the ecosystem level. Fundamental to our understanding of biodiversity is the recognition that these levels and components are all interconnected. Thus, a change in any element of biodiversity, such as that created by the addition of trees into an agroecosystem, will have effects throughout this mosaic, making the prediction on the biological integrity a difficult, if not impossible task.

An excellent overview of biodiversity and ecosystem function in agricultural systems is pre-

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sented by Swift and Anderson (1994). Agricultural ecosystems are unique in that they are characterized by the intense intervention of man; an intervention which moreover generally results in the purposeful reduction in the species richness of the system (Figure 1). Agricultural efficiency or the quest for maximum yields, specifically in the north temperate zone, has led to what are essentially large monocultures (=loss of plant biodiversity) and the intensification of resource use, which includes agrichemicals (e.g. pesticides, fertilizers) and high tillage. These practices further alter above-ground herbivore food chains and below-ground systems which result in loss of whole system biodiversity (Altieri 1991, Paoletti et al. 1992, Pimentel et al. 1992, Swift and Anderson, 1994). This bio-simplification has produced an agricultural efficiency but at the cost of losing natural checks-and-balance functions (e.g. nutrient cycles, biological control of pests, soil quality) necessary for system integrity. The loss of these functions further spiral into an ever-increasing reliance on external inputs to maintain production levels, with ever-increasing environmental damage to the system and difficulty in maintaining production levels.

Table 1 — Conceptual breakdown of biodiversity by levels and components.

Levels Of Biodiversity	Components Of Biodiversity: Compositional	Structural	Functional
Genetic	number of genes, alleles	genetic structure	recombination, evolution
Species	number of species	species distribution & abundance	trophic levels, life histories
Community or Ecosystem	number of communities, ecosystems	habitat structure community distribution & abundance	ecosystem processes

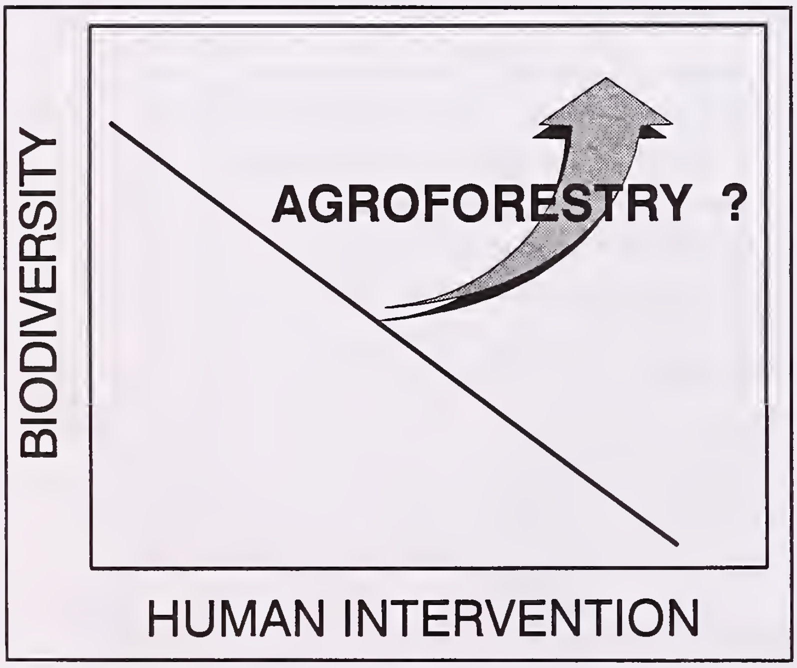

Figure 1 — Generalized relationship between the amount of biodiversity and the amount of intensity of human intervention.

The growing awareness of the many natural roles or functions necessary to maintain ecological sustainability has prompted a reexamination of agricultural management impacts on biological diversity. Before agricultural management can incorporate practices to conserve or enhance diversity, several questions need to be addressed. First and foremost, is the question of whether that part of the ecological theory that states diversity yields stainability will hold true in intensively managed systems, such as that existing in the Great Plains. Second, what are the specific land management goals that we are hoping to attain by altering the biodiversity (See Figure 2)? And, third, what are the right KINDS and the right AMOUNTS of biodiversity needed to meet these land management goals?.

It must be recognized that the processes responsible for natural system sustainability are not the same as those required for increasing the productivity of agroecosystems(Giampierto 1994). In promoting the benefit of increased biodiversity provided from agroforestry systems, we are, in essence, applying a theory which describes naturally-selected ecosystems to a man-made agricultural system. It is unfeasible, if not impossible, to reconstruct the complexity of the natural ecosystem, which for the Great Plains would mean reverting back to the "Buffalo Commons" native grasslands environment (Figure 2). Rather than protecting the ecosystem to save the biodiversity contained within (e.g. the tropical rain forests), the land management goal in agroecosystems is to use biodiversity (i.e. agroforestry-enhanced biodiversity) to protect or save the agroecosystem. By adding the right kinds and

amounts of biodiversity to agroecosystems, certain desirable qualities possessed by natural systems can hopefully be captured in agroecosystems that will enable an economically-sound and environmentally-acceptable production to continue.

Agroforestry-Altered Biodiversity: The Good, The Bad, And The Unknown

"Agroforestry, with its concomitant impacts on diversity, is like a cue ball being shot (and by a very novice pool player at that) into a rack of numerous balls. You're guaranteed that at least one of the balls will go in a "good" direction. But you are also guaranteed that many of the balls are going to go off in various random directions whose individual benefit or detriment to you is unknown until they stop rolling! In nature, they can be rolling around for a long time!"

M. Schoeneberger, August 8, 1994

Biodiversity in the agricultural ecosystem is influenced by landscape structure, field area and margins, as well as polyculture (Paoletti et al. 1992). It is readily apparent that agroforestry - the deliberate manipulation of woody plants in agroecosystems - will influence all these factors, and thus, regardless of intent, will increase biodiversity. The introduction of woody plants into the agrolandscape produces an immediate gain in structural and genetic diversity tied to the plant materials themselves. Biodiversity is further increased through the impacts these plantings

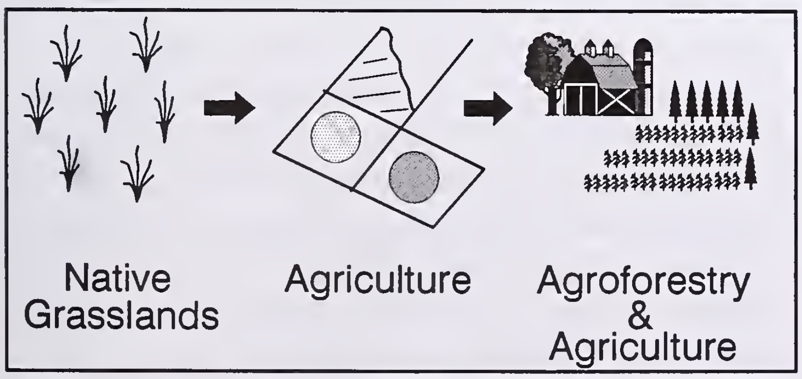

Figure 2 — Biodiversity management goals may be to recreate or restore the native system in order to save the native biodiversity, or it may be to use biodiversity, such as that afforded by agroforestry, to save the system.

have over time in attracting and/or establishing other plant and animal communities ranging in size and diversity from microbes to large animals. Work within the Great Plains (Dix 1993, Johnson et al. 1993) indicate that windbreaks and other woody cover near crop fields increase diversity and abundance of birds, mammals, and certain arthropod predators in fields and field edges. Along with the readily recognized shift in species, the addition of trees to the agrolandscape results in numerous other shifts, running the gamut of biodiversity components and levels (Forman and Baudry 1984). As can be seen in Figure 3, the placement of trees in the landscape produces ecological ramifications beyond just the targeted ones for which they were planted: some of these may be good, some of these may be bad, with the reality that many of them are as yet unknown!

Wildlife Habitat

Enhanced wildlife habitat is a readily recognized and usually appreciated "by-product" of agroforestry plantings, particularly shelterbelts (Schroeder 1986). Along with providing the habitat needs for ring-necked pheasant, gray partridge, fox squirrel and white tailed deer, agroforestry plantings also serve as critical oases for numerous grassland and woodland birds, as well as migratory populations. Readers are referred to an earlier article in these proceedings that covers this topic more indepth.

Biological Control

In modern agroecosystems, research suggests that plant diversity or polyculture can be utilized in pest management, particularly in the enhancement of natural enemies of crop pests (Cromartie 1991). Studies have shown that the habitats created by agroforestry plantings support a larger and more diverse population of natural enemies, like birds and predatory arthropods (e.g. spiders, ladybugs) than monocultures. The effects of these "non-crop" edges may range from providing food for pest predators during low infestation periods;

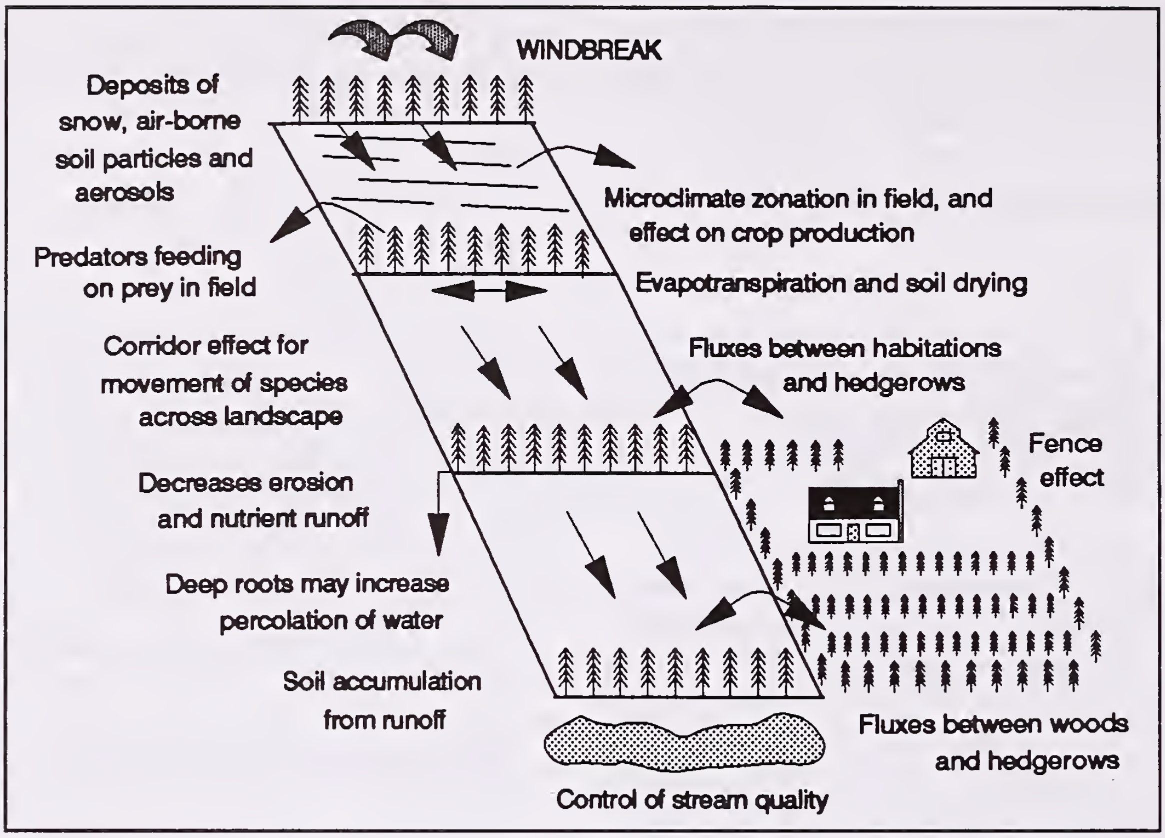

Figure 3 — Overview of ecological impacts throughout a farmscape created by agroforestry plantings (modified from Forman and Baudry, 1984).

providing breeding and overwintering habitat, to modifying wind speeds and patterns. They have been found to serve as important reservoirs of predatory arthropod species that feed on crop pests such as cereal aphids. In one study, predator numbers decreased with increasing distance from the non-crop edge and were inversely correlated with numbers of aphids (Dennis and Fry 1992).

The most successful practice to date in which agroforestry is utilized for biological control of crops is in California where *Rubus* sp. are planted around grape vineyards for the control of the grape leafhopper. These plantings serve as critical winter refugia for the parasitic wasp responsible for biological control of this economically important pest of grapes (Doutt and Nakata 1973). The close proximity of *Rubus* enables the wasp to maintain a population level that can readily invade and quickly build up in numbers to provide significant control of the grape leafhopper. This practice has been further refined in that it was found prune trees serve as an excellent alternate habitat for the parasitic wasp. If planted upwind from the vineyard, the prune tree plantings not only provide effective biological control of the grape leafhopper thus reducing pesticide use, but also provide an additional cash crop of prunes the farmer can harvest.

Research by the University of Nebraska and the National Agroforestry Center is evaluating impacts of tree shelterbelts on the abundance and diversity of tree and crop pest and natural enemies. Data from 1992 and 1993 muskmelon study showed that parasitic wasps, a natural enemy, were more abundant and cucumber beetles and corn root worms, crop pests, were less abundant in sheltered than nonsheltered plots, respectively (Hodges et al. 1994). Further work is needed to determine whether the addition of trees to the system provides a level of predation that can delay or remove the need for chemical pesticides, and whether this benefit can be reliably managed for in specific crop/agroforestry systems. Integrated pest management using agroforestry plantings will necessarily have to be based on an understanding of the trees and their development, the crop and its development, the natural enemies and pests of both trees and crops, and the interactions among all these components (Figure 3).

Riparian Buffer Performance

The ability of riparian buffer systems to mitigate nonpoint source pollution is in large part dependent on the microbial activity that occurs belowground. The microorganisms function to either immobilize, breakdown, or convert, or otherwise filter out the pollutant before it can enter the surface or groundwater. As human intervention increases, belowground microbial activity is severely impacted. In a sequence representing different degrees of human intervention on vegetational cover (e.g. evergreen oak to cereal crop), Garcia-Alvarez and Ibanez (1994) found total microflora, actinomycetes, fungi and algae decreased as intervention increased. Even within disturbed systems, those having more plant diversity were found to have greater microflora quantity, diversity, and activity, as measured by enzymatic activity (Bopiah and Shetty 1991). By selecting and interplanting a mixture of woody plant species that promote rhizosphere populations and activities we should be able to greatly enhance the performance of riparian buffer systems.

It should be readily apparent that through correct management, riparian buffer systems could function in providing all three of the above listed biodiversity benefits: enhanced wildlife habitat, enhance natural enemies of crop and tree pests, and mitigation of nonpoint source pollution, as well as others to the landowner (i.e. wood products).

The Bad And Unknown

The sections above have pointed out some of the potential benefits afforded by agroforestry-enhanced biodiversity. However, the diversity created by these tree/crop interfaces can also be detrimental to landowner goals if not managed for correctly.

The woody networks also serve to host pests as well as natural enemy populations. In England, the ecological benefits of hedgerows are well recognized and numerous tree planting programs exist to promote creation of woody interfaces within the environment (Inglis et al. 1994). The creation of new woody plantings on farms could also enhance numerous pest species, including the economically-important pest of oilseed rape, the wood pigeon. Given the number of woodpigeon nests are a function of forest edge, woodpigeon populations should be minimized if tree planting is targeted as additions to existing plantings to minimize edge length created versus creating new plantings. Likewise in Texas, cottonbole weevils, an economically significant pest of cotton, was found to overwinter in shelterbelts near cotton fields. Minimizing ground litter duff under the trees eliminates this overwintering habitat, thus reducing this deleterious effect while maintaining the other benefits afforded by the shelterbelts (Slosser et al. 1984).

While the work on muskmelon, that was reported on earlier, found shelterbelts enhanced the quantity and quality of certain natural enemy populations, it also found that sheltered conditions increased small animal populations. These creatures caused considerable cosmetic damage to the muskmelons, which for this crop represents a significant economic loss (personal communication). How this can be managed for is as yet undetermined. Further, shelterbelts enhance wildlife habitat for some species, but may be detrimental to other species, especially grassland species, by providing habitat for predators that prey on these species (Knopf, 1992).

Impacts of agroforestry plantings on the ecosystem may not be readily evident if they are not directly observed. For example, Sweeney (1993) points out that the selection of the plant species for the riparian buffer systems can dramatically influence the fisheries habitat by altering the quality of food available to the macroinvertebrate populations that the fish feed on. His studies also indicate that a mixed, native species composition support a wider variety of macroinvertebrates than a monoculture or exotic woody plant composition.

Ecological impacts of agroforestry-enhanced biodiversity may be limited to a specific tree/crop interface or, given these fragmented, linear forests serve as biological corridors, the impact can become watershed- to region-wide. Thus, fore-

knowledge of as many impacts as possible is needed if we are to practice "safe" agroforestry.

Agroforestry-Enhanced Biodiversity: Management At What Scale?

"To maintain the landscape in good health, it is not necessary that every landholding, every stretch of land, contain trees, just as every farmer need not be an agroforester - but it is necessary that there be sufficient trees in the right places, at the least on sloping land and along streams."
Thaman and Clark (1993)

Enhancing the biodiversity of agroecosystems includes more than just adding species. It encompasses creating or recovering ecological processes or functions performed by those species that are essential to the internal functioning or sustainability of that system. Management practices to enhance "targeted" biodiversity may be implemented at various scales from field to region depending on the goal (Figure 4). Enhancement of arthropod biological control populations (i.e. spiders) is logically managed at the specific tree/crop interface level. Agroforestry plantings for wildlife conservation or enhancement of vertebrate biological control populations (i.e. birds) will necessarily be implemented on the per farm basis due to the nature of the landownership and the planting programs but must be managed or planned for at the landscape if it is to be successful (Saunders 1994).

Barrett and Peles (1994) argue that in order to enhance biodiversity, while implementing a more sustainable type of agriculture, management must be at greater spatial and temporal scales than normally conducted (i.e. the farm). The functional significance of biodiversity that determines a system's integrity is tied in at the landscape level. For this reason, planning based on isolated components (i.e. individual plantings versus the agroforestry system created within a watershed) will be ecologically incomplete.

Federal, state and local agencies are now advocating that environmental management be conducted at the watershed scale. Therefore, the value of a riparian buffer strip, in terms of mitigating nonpoint source pollutants, wildlife, and other benefits, may only be realized if managed and planned for at a scale greater than the per-farm level it is planted on.

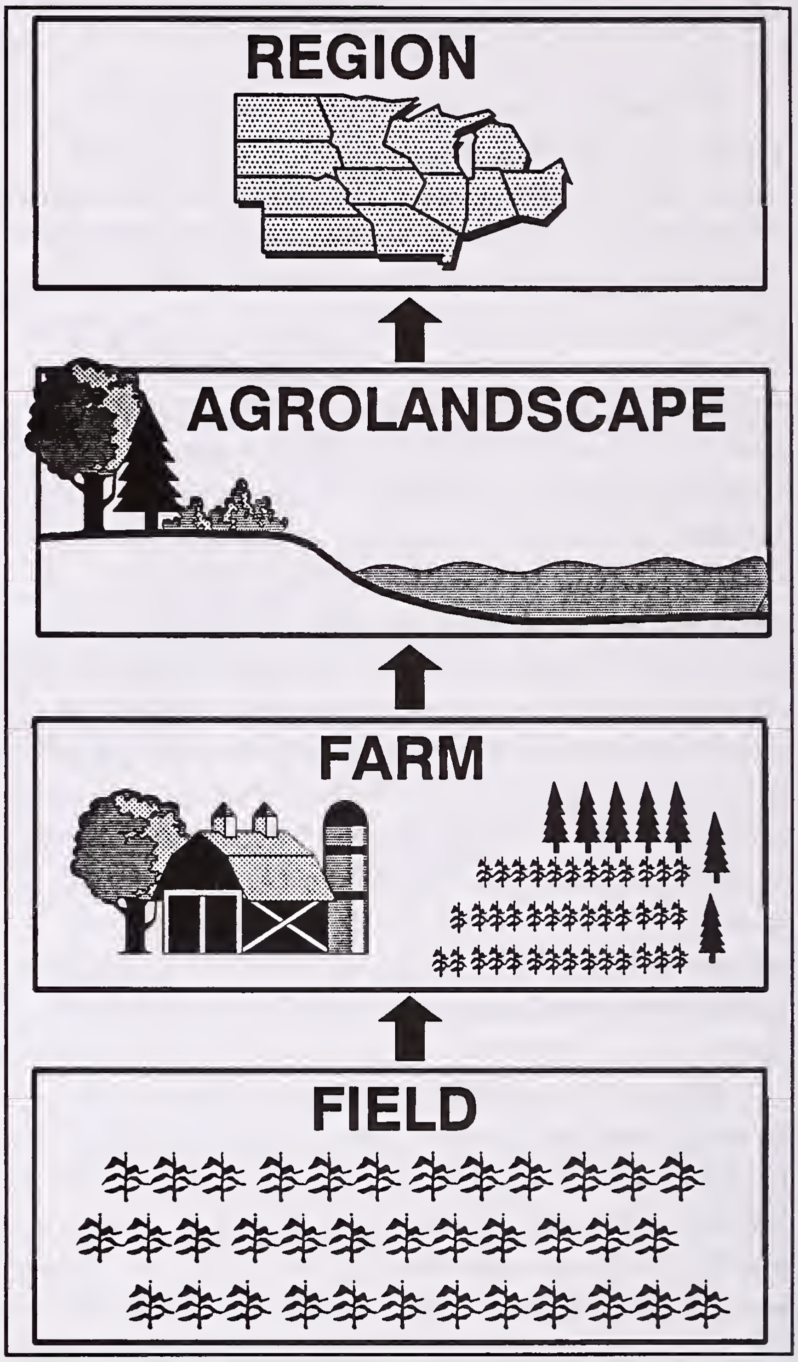

Figure 4 — Ecological ramifications of agroforestry plantings occur at and must therefore be managed at multiple scales ranging from the field upwards.

The Cost Of Biodiversity: Who Pays For It?

"What is unreasonable is that a few individuals should pay for a benefit which accrues to society as a whole."
Rookwood (1995)

The potential for agroforestry to purposely promote biodiversity and enhance agroecosystem integrity is great (see other pertinent articles in proceedings). Obviously, implementing agroforestry for biodiversity purposes has social and economic implications as well as the ecological ones discussed earlier. The dilemma exists that policies and management are currently conducted at the landowner/landholding level rather than at the agrolandscape level where the environmental processes are integrated. The two problems that must then be addressed are 1) the knowledgeable implementation of agroforestry at the watershed and larger scales and 2) the issues of equity in promoting agroforestry (i.e. the cost borne by the individual landowner implementing agroforestry versus those who receive the benefits) (Thaman and Clark, 1993). While much information is still needed on the ecological interactions, tools are now available, including GIS, remote sensing, and decision support systems, that will enable agroforestry to be blended and balanced within the agrolandscape for optimum benefit. The more difficult problem remains to be the political and social constraints we currently work under for land management. Furthermore, there is a tremendous time-lag in realizing the benefits gained by agroforestry-enhanced biodiversity, that can negate the return the individual may receive on today's investment in conservation.

Costs of promoting agoforestry should be equitably distributed to all who share in its benefits. With our current knowledge, agroforestry systems are best promoted for the direct returns that the individual landowner can reap, such as crop yield increase, homestead energy savings, and wood products. The biodiversity benefits, if managed for at all, are usually limited to those involving game species (e.g. pheasant) or proven biological control systems (e.g. grape leafhopper control by woody plantings) which directly benefit the landowner. As our skills to reliably predict the impacts of agroforestry-enhanced biodiversity on agroecosystem sustainability increase, better information will be available to determine where within a watershed agroforestry planting benefits are optimized for the individual landowner and for the public at large. By being able to identify where within a watershed or another unit of land management agroforestry systems would provide the optimal economic and ecologic returns to the individual landowner and to the public at large, cost-share programs could more effectively meet their goals while equitably distributing the cost of attaining a more sustainable agroecosystem and beyond to all.

Conclusion

"Biodiversity is a way to hedge bets against uncertainty, even in managed systems."

(Tilman, as quoted in Baskin 1994)

Enhanced biodiversity in agroecosystems is one of the key elements in attaining a more sustainable system and is being touted as one of the many benefits from agroforestry. Swift and Anderson (1994) point out that "the case for greater stability or sustainability still remains to be made, but the indications are promising". Agroforestry systems will continue to primarily be implemented for specific benefits, such as, yield enhancement and energy savings from windbreaks. The capability to integrate a wide array of multipurpose woody plants and planting designs within agricultural landscapes makes agroforestry a flexible and therefore powerful tool for manipulating and therefore capitalizing on the resultant beneficial shifts in biodiversity. Current knowledge enables us to make some "best guesses" on what the designs and subsequent impacts of agroforestry plantings will be in the landscape. Complete knowledge of the numerous and complex impacts at any scale are currently beyond us. Agroforestry plantings already offer distinct benefits to the landowner and beyond (i.e. enhanced crop yields, erosion control, enhanced water quality). As these practices are developed and implemented for these identified benefits, work will need to continue to elucidate all impacts that feed into the biological integrity of the agrolandscape so that the bad ones can be minimized and the goods ones maximized.

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Learning From the Future: Sustaining Our Food, Natural Resources, and Environment[1]

C.A. Francis, J.W. King, and J.M. Brandle[2]

Abstract — Current challenges of human overpopulation, unrealistic and unequal standards of living, finite supplies of some natural resources, declining quality of the environment, and growing incomes and aspirations in third world countries must be addressed by scientists and development experts. The results of unrestrained human population numbers, neoclassical competitive economic systems, and nationalism are causing many people to question the paradigm of human success through continuous growth in consumption and economies. We need a new approach to food, resources, and the environment.

Business as usual will not be sufficient to sustain our current standard of living, and in the future will not assure survival. It is not enough to learn from the past, to project trends through the present into the future, and to depend on human cleverness and new technologies to overcome any unanticipated consequences of the growth paradigm. A more powerful alternative is to recognize the discontinuous and unequal process of change among different societies, understand the causes and effects of adopting specific technologies and production systems, and carefully choose those components and systems that will move a society in a desirable direction. The future consequences of many decisions can be observed somewhere on the planet, if we are willing and able to find and measure them. Thus, we can "learn from the future" and begin making rational decisions about the most desirable directions for humans to pursue to sustain a food supply, the natural resource base, and a livable environment.

To learn from the future means evaluating what is already being done to create a more sustainable food system, sustain the natural resource base, and enhance the environment. It means gleaning wisdom from the past, as well as analyzing the present and casting past wisdom in a new light using new tools and visions for sustainability. It means discovering exemplars in our bioregions and using these in designing future-oriented activities, listening and hearing, and uncovering truths about natural systems. Learning from the future also means thinking ahead, as Native American groups evaluated impacts of major decisions on seven future human generations, or a span of at least 150 years, as part of their planning process. This approach means developing a vision of a desirable future, and making decisions today to cause that future to happen.

Introduction

To learn from the future appears at first glance an oxymoron. How is it possible to learn from what has not yet occurred? Yet we recognize that development or change of any kind is a discontinuous process, that speed of change is different in diverse places in the world, and that these differences are related to the natural resource base,

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human population, current level of technology, and stage of economic development. It is likely that many of the changes being considered in any one place have already been tried somewhere else.

If we accept this premise, then the future — with respect to causes and effects of most specific introductions of technology or other elements of social change — has already happened somewhere on the planet under some other set of circumstances. If this is true, we can observe the impact of that change, eg. learn from their history. In essence we can project our own future in this time and place. The history of that other time and place becomes relevant to our future, and thus a potential to "learn from the future." In fact, it is not just "future," but rather "futures" for there are many pre-existing alternatives and sets of circumstances in the environment. It is from these current histories that we can learn from the future.

Three major hurdles stand in our way. One is a general unwillingness to plan ahead more than a short time; for example, in farming failing to think beyond the current growing season; in communities the problem of considering the social consequences beyond the immediate impact of new industry creating a number of jobs for construction of facilities. The long-term economic or social impacts of those changes either elude us in the planning process or are deemed a necessary consequence of change toward the future. Given our current economic accounting system, for example, "Glowing economic reports are possible even as the economic policies that generate them are destroying the resource base" (Brown, 1984). Many Native American groups followed a seven generation philosophy; major decisions were considered in terms of their impact on the group for seven generations into the future. This is far different from our single-season plans in farming, four-year strategies for universities, or five-year plans for national development. The seven generation philosophy projects consequences about 150 to 200 years into the future. For most of our current programs, thinking and planning in short time frames is the norm.

A second major hurdle is the heavy reliance on individual property and resource ownership and decision making in Western societies as the best approach to human survival and progress. This assumes that the collective success of individuals who follow this approach will lead to success for the entire community. Although there has been substantial change in health and standard of living for many in today's "modern" societies, these benefits have in no way begun to reach all members of each group. Two recent contrasting opinions about the importance of private property owners rights describe the current dilemma in the U.S. (Berle, 1994; Tauzin, 1994). Again, the Native American community and many others in what could be considered "developing" societies do maintain a sense of equity among the members, and decisions are made within the framework of their impacts on the entire community. With a "frontier" mentality and relatively low human population density, many in the U.S. have assumed that natural resources were inexhaustible, This would clearly be an error given today's understanding of resource consumption by a growing human population (Hammond and Estes, 1994).

Finally, there is a general acceptance of dominant, social and technical trends. We assume the arrival of that trend-dominated future, whatever it may bring, causing our needs to adjust to trend-based certainties. We strongly disagree with this assessment, arguing that we can choose to develop many "futures" according to whatever criteria seem appropriate. In essence, it is possible to "design the future" and to make decisions starting today to cause these more desirable futures to happen.

We are proposing a profoundly new approach. We believe that people can learn from the future, begin to project impacts of decisions beyond the short term of a few years, make decisions based on the goal of an acceptable quality of life for humans while minimizing the negative impacts on other species, and determine that the future is something that can be designed and shaped. Based on this futures approach to thinking, we believe that it is possible to move in more sustainable directions in development.

In this futuring context, we need to explore

definitions of sustainable agriculture, forestry, agroforestry, and development. It's also important to explore the process that can lead to meaningful education about the process of change. How can people become empowered to make positive change occur? What are some specific examples of change that can illustrate the above goals and processes? These issues are explored within the context of sustainable agroforestry and development.

Defining the Scientific Context

According to a recent survey of extension agents and specialists about perceptions in the arena of education about future systems, the most frequent question posed by farmers and others in their communities was "What is sustainable agriculture?" (unpublished data). It is likely that the same uncertainty exists around the terms agroforestry, agroecology, and sustainable development. Although the recent literature illustrates an abundance of thought and energy devoted to definition and practices, there is still much public debate and concern about these terms. Many of these definitions are included in the reviews by Edwards et al.(1990), Francis et al. (1990), and Hatfield and Karlen (1994).

Agroforestry could be defined as a system that "Puts trees to work in both rural areas and communities," with the goal of using "working trees to help make agriculture sustainable by conserving natural resources, increasing crop and livestock production, and improving human environments" (CSAF, 1994). This definition stops short of ensuring preservation of non-human species as a critical part of ecosystem structure and function.

In a broader definition, sustainable agriculture could be considered "A philosophy based on human goals and on understanding the long-term impact of our activities on the environment and on other species. Use of this philosophy guides our application of prior experience and the latest scientific advances to create integrated, resource-conserving, equitable farming systems. These systems reduce environmental degradation, maintain agricultural productivity, promote economic viability in both the short and long term, and maintain stable rural communities and quality of life" (Francis and Youngberg, 1990). A summary definition that expresses a broader dependence on other species is "An agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use, and a balance with the environment that is favorable both to humans and to most other species" (Harwood, 1990).

Sustainable development in a larger sense must address the questions of global resources, human population, natural environment, and social equity. To sustain the human population for an indefinite future, we need to consider at least the following issues:

- resource use efficiency: a food system needs to become increasingly reliant on renewable resources including contemporary energy, and substitute these renewable resources for those that are limited such as fossil fuels and other extracted elements.
- profitability for those involved in the food system: both in the short and long terms, a system needs to include incentives to bring young farmers and entrepreneurs into the food business, and we need new measures of accounting that include evaluation of the long-term costs of food and other production outputs; in a global sense, there are no externalities.
- environmental soundness: there is need for an evaluation of the positive and negative impacts of each potential human food system in relation to quality of life for all in our species and survival of most other animal and plant species.
- social viability: equity of access to food and production resources, viability of life in rural areas and small communities, and impacts of agriculture on people in both labor and management are part of the social fabric that is tied to the food system.

Global attention has been brought to these issues as a result of the 1992 Rio de Janeiro conference on sustainable development and the resulting Agenda 21 Report (Robinson, 1993). Both

contain strong appeals for world cooperation in the quest for a sustainable future.

Defining the Social Context

Change is part of the natural order, in biological systems and human societies. The following definitions of change are useful to this discussion:

- change: "...any planned or unplanned alteration of the status quo in an organism, situation, or process..."
- planned change: "...an intended, designed, or purposive attempt by an individual, group, organization, or larger social system to influence directly the status quo of itself, another organism, or a situation..." (Lippitt, 1969)

Changes are often called shifts, variations, alterations, modifications, adjustments, growth, or evolution of a system. Most relevant to this discussion of learning from the future to create a sustainable pattern of development is that change is a process. It is discontinuous, proceeding at different rates in distinct places around the planet.

Certain circumstances of change are processes. They are the total action of change, from the origins, to the transformation itself, to the impact of the change. Examples of change include the forest fires in Yellowstone Park, or cropping pattern shifts as a result of federal programs or relative prices, or riparian zone modification of water flow and quality in the Platte Valley.

The process of change can be purposeful, as when we introduce a new species into a cropping system (amaranth as a cereal grain in traditional corn areas), or when we teach a new farming technique (introduction of ridge tillage to minimize energy costs of crop production). Planned change may result from a learning event, such as an Extension meeting geared toward increasing the appreciation for good record keeping and the shift in enterprises as a result of better production cost and crop price information.

Change can also develop inadvertently, such as when an introduced species "escapes" or causes unanticipated damage, such as the Kudzu invasion of the Southern U.S. or the arrival of the starling that displaced a number of songbirds in North America. People can experience unexpected change, as when they win a prize, or when they learn something by "osmosis," an absorbing of information from some nearby but unidentified source.

How do we deal with change? We argue that people can be driven by change and react to it; we can let trends push us, and we can "solve problems." However, we believe that another, more future oriented approach is to look for opportunities; we believe that people can go beyond problem solving to search for innovative efforts that can be used to fashion new systems. In our current drive toward sustainable systems, we look for people and projects already engaged in changing the system (Barker, 1992). Some of these individuals and activities are challenging the basic tenets of what the system does; some of them are reinventing old strategies in new ways or applying old techniques to new systems; some of them are developing new linkages to new information and thus seeing and discovering new opportunities in existing situations. Whatever the case, the shift from problem solving to looking for opportunities is fundamental to learning from the future.

Examples of Change as We Learn From the Future

Within this scientific and social context, it is useful to explore some specific examples of change and how this allows us to learn from experiences of others, in space and time, and build on this experience base in designing our own sustainable future. Seven examples are presented.

Teaching and Learning Environment

Important to learning from the future are teaching and learning (Francis and King, 1994). It is through teaching and learning that many

human activities and behaviors change. For example, an elder "teaches," models, shows, discusses, or demonstrates things to others. A learner learns, understands, discusses, watches, tries, or practices that something. Resulting processes may be those which were never tried before. They may have positive or negative results for the individual, the community, or the environment. A learner changes because of the experiences — planned or not planned, intended or unintended by the instructor. Because of the learner interaction, the instructor too may change. The teacher, in fact, may be a book, a machine, or an experience. One characteristic of change in both teacher and learner is its rapid and broad occurrence. Even announcements of impending change can cause shifts in behavior, before the actual change itself occurs. Pushed by technological and social change, all facets of education and society are modified.

Many of us view our teaching and learning environments as stable; yet change has intervened. In agroforestry settings, we are moving away from one-way, teacher-to-learner models, for example, from extension specialists-to-framers to more collaborative educational forms. A recent FAO (1993) publication describes training in social forestry, participatory forestry, and community forestry as new dimensions in education. These evolving learning environments require people to learn together in collaborative sharing situations in classrooms, fields, and on-line. We believe that new transforming methods and techniques, innovative approaches, and participatory teaching and learning strategies are being carried out now in many farmer to farmer programs. "Co-design" of learning environments is one desirable new strategy (King et al., 1989). We have to seek out and identify other individuals and projects and learn from them.

Components and Systems Perspective

The majority of research and development activity in recent decades has been on components of agricultural production or food processing systems. Research projects on crop breeding, yield response to added fertilizer, or efficiency of irrigation methods are good examples of vital component research that has increased productivity and reduced cost. Our graduate education likewise has focused on teaching components in discipline-specific departments such as Agronomy, Entomology, or Economics. Success of this research and education effort has been demonstrated in the high labor productivity and low food cost in most developed societies.

Only recently are we becoming aware of the broad environmental, natural resource, and social consequences of looking separately at unique pieces of the system (Edwards et al., 1990). When the focus is only on higher rice yields, the long-term environmental costs of pesticide infusion into surface waters and social costs of migration of rural people to already overcrowded cities are not a part of the economic evaluation equation. When we buy dimension lumber from a discount store the price likely reflects the short-term efficiency of clearcutting a forest in the Northwest U.S., and not the long-term cost of restoring that damaged ecosystem. A new system of biological and economic evaluation is needed to take into account these total costs of human activity.

Emerging in our research and education institutions is an appreciation that a better approach is through the study of integrated systems. Research on crop rotations, spatially diverse cropping patterns, and integrated crop/animal systems is providing an integrated look at the complexity of interactions among system components. Examples of books that synthesize the systems perspective have been published recently (Edwards et al., 1990; Francis et al., 1990; Hatfield and Karlen, 1994). Education is taking the form of courses in agroforestry, agroecology, bioethics, and economics of integrated systems. A new course in Nebraska required of all new students in the College of Agriculture and Natural Resources introduces them to the complexities of food systems as part of the larger economic and social context. They grapple with the value systems that drive our decisions about food, human health, natural resources, and the environment.

Technical journals in specific disciplines are becoming more friendly toward systems-oriented papers in research and teaching, and new journals such as *Choices, Journal of Sustainable Agriculture, American Journal of Alternative Agriculture, Agricultural Systems (UK), and Agriculture and Human Values* have emerged that represent a number of technical societies and focus areas. This is a major shift toward integration of components into cropping and food production systems.

Roles of Individuals and Communities

Learning from the future will also mean a change in the role perceptions of individuals and communities (Flora, 1990). Traditionally, we spend most of our time and concern discussing absolute individual rights and property, and some authors identify such issues as the key driving forces and core values behind political and economic decisions (Cubbage and Brooks, 1991). In new, evolving models such as social agroforestry, people are exploring how to incorporate a larger reliance on the community for decisions. Because much of our natural resource decision making will take place in the context of watersheds or ecoregions, this decision making will have to involve more than isolated individuals. In larger systems, communities of individuals will gain in importance and their role in decision making will be seen as more critical. Communities will, in fact, be required to participate in natural resources decision making. We consider this growing reliance on communities for decision as essential for enabling the growth of agroforestry and sustainable systems.

Ideas on Technology Transfer

Technology transfer too is being reconceptualized. From our older views of "us-to-them, top-down approaches," we are moving to conceptions of partnerships, teamwork, and public involvement. Chambers et al. (1989) suggest some ideas in their book, *Farmer First*. Technology transfer is beginning to take place in an environment of interactive communication, that is, questioning environments, open settings, and frank objectives and truthful agendas. Agroforestry teams now search out opportunities, rather than simply responding to problems. Individuals form new professional and social relationships; people share in new learning environments which they help construct. In such situations, technology transfer becomes a multi-way transfer. Improved models of technology transfer accommodate participation, developing strong interactive communication in place of traditional one-way social conventions.

Equity Issues

There will also be a change in equity, both intergenerational and gender. This means a shift from a high concentration of wealth among older people and decision making by a few to a more equitable distribution of resources and skills within the entire farming and ranching community. Questions of long term thinking and impact may be different to a 58 year old farmer than to a 31 year old. Corn versus trees, annual returns versus the future are some of the conflicts to be considered. Often older farmers are left out of newer programs because centralized planners feel some older farmers aren't willing to change, or they are not innovative. History shows, however, that many older producers have the real world experience to take leaps of faith; they often have the organizational and negotiation skills to carry out change.

Our vision is that the concept of young and old must expand. Today's prevailing generational and gender ideas are largely remnants of early 20th-century expressions of our then agricultural society. We now need broad based, inclusive programs to enable generational and gender equity to become a shared value and a real force in the future.

In examining future oriented projects, we should see how they use older farmers; how young farmers move into leadership arenas; what

old, agroforestry ideas persist because they are good and unique for a particular watershed; what roles women are playing in organizations and efforts. Taking the best of each of these, we learn from the future.

Anticipative Decision Making

Much of the focus on learning from the future is anticipative in nature, as compared to short-term problem solving or 'putting out brush fires, common approaches to practical research and education in today's environment. A number of educational groups have produced five-year plans and vision statements for the future (DeBree and Vance, 1994). In these visioning activities, as well as listening sessions with clients around Nebraska, we find that most people are clearly focused on problem solving for immediate challenges. Agricultural concerns center on government regulations of specific pesticides or erosion control measures, while communities discuss where to dispose of solid waste or how to control crime. Even plant breeders who are working toward long-term genetic changes in crop hybrids seem preoccupied with today's systems and production constraints (Francis, 1980).

Anticipative decisions are those that look at current challenges and how these will influence the farm or the community in the future. Rather than waiting for problems to occur, the alternatives for the future are considered along with their consequences, and the most rational route chosen to avoid problems rather than waiting for them to happen. To avoid the problem of government regulation against Atrazine herbicide, a farmer could opt to use reduced primary tillage to suppress weed populations and mechanical cultivation to control those that escape and compete with the crop. A community could launch a massive education and reduce/recycle/reuse program that would drastically reduce the need for a large place for solid waste disposal. Land owners in a watershed could organize contiguous planting of wildlife cover areas so that animals can easily move across the landscape, rather than waiting until a species is near extinction and requires federal legislation for protection. These are examples of how change can be anticipated, and decisions made by learning from what has been done in other places: their past, but our future.

Short Versus Long Time Frames

Cropping decisions most often are made from year to year; crop choice, cultural practices, timing of operations are considered within the framework of the farm today and the projections for the coming season. We elect officials for one to six years, and most planning time frames are within five years of less. This behavior can help us fine tune current approaches and systems to changing economics and short-term vagaries of weather. Yet this tactic does not influence the long-term sustainability of systems, except in a very piecemeal way.

Native Americans studied major decisions to be made by the community in terms of their potential impacts on the next seven generations of people in that community. This time frame was 150 to 200 years. Whether more land would be farmed, greater numbers of animals killed during the hunting season, or a village should be moved were put into the context of several generations. For a society that lived in close proximity and dependence on the local natural resources, this decision making and planning approach made sense. As we have become more removed and protected from the natural environment, we lose sight of these dependencies. Yet they are very real! Although we import a substantial part of our fossil fuel energy from other parts of the world, this creates a fragile dependence on international politics, currency exchange, and transportation systems. We wait until there is an oil shortage caused by political change, or a scarcity of lumber for building due to exhaustion of the source before we seriously consider research and development on alternatives. Especially in the design of long-term strategies such as agroforestry systems, it is critical to take an extended view of challenges. The expense of installing woody perennials as part of a system needs to be charged to the cost of food and the appreciation of any environmental benefits that would accrue.

Changes in the Domination Mentality

Western society has evolved over two millennia with a perspective of domination of the natural world to provide for human needs and wants. One of the more articulate recent challenges to this paradigm has come from writers who identify with "deep ecology" (Jacob, 1994). This is a world view that considers our relationship to nature and to our value system as it relates to other life forms. Such people as Henry Thoreau and John Muir, philosophers and visionaries in their time, were deeply religious in their ecological views about the connectedness of God and Nature (Sessions, 1993). In summary, the believers in deep ecology challenge not the ability of humans to understand and dominate the natural environment, but the value system that allows humans to set themselves above and apart from other life forms. Their ecological consciousness extends to development of strategies that will ensure meeting human needs while supporting the survival of all other existing life forms. A deep ecologist would further argue that our own human survival likely depends on a better appreciation of other species, and that a sustainable ecosystem needs all of these components even if we do not currently understand the function of each of them.

Soule and Piper (1992) examine the potentials of developing productive agroecosystems that depend on perennial polycultures, mixtures of plant species that emulate the native prairie that they replace with food-producing plant species. Maser (1994) describes alternatives to current forestry practices, and what must be done to establish a sustainable forestry production system. And finally Jackson (1994) applies the concept of deep ecology to his philosophy that we can learn from the native vegetation and animal species about what type of production system is best suited to that place. He postulates that a crop/animal ecosystem has evolved that is uniquely suited to each site, and that our better understanding of the components and interactions within a natural system can provide guidelines for design of productive agroecosystems.

These are examples of changes in thinking that are taking place among academic groups, environmental organizations, people in rural and urban areas, and future planners. The process and the potential outcomes are drastically different from the current systems we pursue for food production. The fact that many of the components and alternative systems have been tried in other locations around the planet should make us appreciate how we can learn from this information research to design our own sustainable future.

Conclusions

Today, the results of not learning from the future will be problematic at best, and catastrophic at worst. Agroforestry systems, the teaching and learning about the systems perspectives and long term views, and the inclusion of community will be assigned leading roles in the move toward sustainable development. As a matter of principle, agroforestry systems will be expanded with successful projects duplicated and adopted for regional impact.

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Economics of Agroforestry[1]

John Kort[2]

Abstract — This discussion will look at the value of trees and shrubs due to their effects and products coming from them. The discussion will review literature concerning agroforestry practices appropriate to the Great Plains States and the Canadian Prairie Provinces. The agroforestry practices which will be discussed will include field and farmstead windbreaks, roadside shelterbelts, maple syrup, fruit production, wood products and tree plantings for wildlife.

Economics of Field Windbreaks

Kort and Brandle (1991a, 1991b) considered most of the economic factors relating to field shelterbelts in the computer program WindBreak ECONomics (WBECON). The program considered mainly the benefits of the windbreaks to crop yields but deducted from these benefits, crop losses due to root competition and land out of production. Shelterbelt growth rates, lifespan and costs of establishing and maintaining the shelterbelts were important variables in this model. Under the scenarios presented in Kort and Brandle (1991b), well-designed shelterbelts had Net Present Values (NPV's) of $1500 to $3000 per half mile under cereal grain production. The values would be much greater for high value crops such as fruit (Norton, 1988) and vegetables (Baldwin, 1988). A computer model reported from Australia called FARMTREE calculates the NPV's of agroforestry systems including shelterbelt crop production benefits as well as wood values and livestock benefits (Loane, B., 1991).

WBECON does not account for residual benefits to soil productivity. A weakness of traditional economic analysis is that future benefits are discounted to such an extent that protecting soil for protecting soil productivity in 50 years does not pay if it is not economical now. Fortunately, windbreaks do result in short-term benefits, justifying their use for long-term benefits. Even so, the reason that most farmers give for planting shelterbelts is soil erosion protection.

Economics of Farmstead Windbreaks

In Canada, trees around farmyards perform the basic functions of trapping snow in the winter, reducing winter heating costs and improving aesthetics and human comfort throughout the year. Trees also give shade and reduce summer costs of air-conditioning.

Two studies on home heating benefits of shelterbelts agree that savings of heating costs are on the order of 15-30% depending on weather conditions and house construction (DeWalle and Heisler, 1988; Moyer, 1990). Assuming average annual heating costs of $1000, the saving is $150-$300 per year. The value of such windbreaks would be much greater for the protection of high energy use structures such as barns or greenhouses.

Huang et al, 1991, calculated the value of large deciduous shade trees in reducing cooling costs in a variety of US locations. The extremes were Minneapolis where savings were $15-20 per year and Phoenix where savings of $85-170 per year were calculated.

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Aesthetic benefits of farmyard shelterbelts are extremely important to prairie families. Although aesthetic values are difficult to separate from the other benefits of snow trapping and home-heating cost reduction, Hart (1991) described a subdivision near Bismarck, N.D. in which vacant lots were protected by 12 year old windbreaks. The average selling price of the treed lots was $16,000 while similar lots in a nearby unsheltered subdivision sold for $6,000-$9,000. A study by Brown and Cherkezoff (1989) showed that a row of spruce trees at Toronto created comfortable conditions on their south side for an additional 466 hours a year compared an unsheltered location and for an additional 201 hours a year on their north side mainly by moderating cold conditions in winter, spring and fall and by moderating hot conditions in summer. The value of shelterbelts for reducing snow-clearing costs from farmyards has not been studied but has been cited by farmers as a major reason for farmyard shelterbelt establishment.

Value of Roadside Shelterbelts

In Wyoming, snow fences along the highway saved about $27,000/km/year (17,000/mi/year) in snow clearing costs (Tabler and Furnish, 1982). Snow fences did not reduce road closure but reduced by more than half the number of accidents due to ground drifting of snow and appeared to reduce accidents related to wind. An estimated 54 accidents per year would be prevented by 90 kilometres (60 miles) of fencing. Shelterbelts are equally effective snow traps and are being used as living snow fences throughout the prairies.

Non-Wood Products from Agroforestry Plantations

Maple Syrup

Manitoba maple or box elder (*Acer negundo* L.) has been used in prairie shelterbelts for many years and grows naturally in river valleys in most of southern Saskatchewan and Manitoba and throughout the eastern Great Plains. This is a true maple and behaves the same way as sugar maple, producing a flow of sweet sap early in the spring. Because the tree is smaller, shorter-lived and more likely to have a significant amount of deadwood than the eastern maples used for syrup, the amount of sap collected from individual trees is less than that of sugar maples. The sugar concentration of the sap is similar to the sugar maple so that the cost of processing a given amount of sap to syrup is similar. The quality of syrup produced in Saskatchewan and Manitoba is very good and can be sold commercially. The question as to whether it makes economic sense to produce maple syrup from this tree depends on the efficiency of sap collection and the price which can be obtained for the product. The key to maintaining a high price is to emphasize the difference between prairie syrup and eastern syrup. In 1994, it is estimated that, in Saskatchewan and Manitoba, sap was collected from 6000 taps in 6 operations and many individuals tapped a small number of trees for their own use.

Fruit Production

Harvesting of small fruits appears to be an emerging industry on the prairies. In the past 20 years, the saskatoon berry (*Amelanchier alnifolia* Nutt.) has made the transition from a wild-picked berry to a plantation-produced commodity via superior cultivar development and developed expertise in tissue culture and plantation management. It is now in high demand in U-pick plantations and saskatoon jam can now be found on store shelves. There are presently about 10-15 small scale processors of saskatoon products such as jams, jellies and syrups in the three prairie provinces. Williams (1991) presented an economic scenario of a 4 hectare (10 acre) saskatoon plantation in which the net income was almost $25,000 assuming a production of 15,000 k (33,000 lbs) of saskatoons. There are currently about 115,000 k

(250,000 lbs) of saskatoons grown annually on the prairies and the industry is expanding (Scholz, 1994, pers. comm.).

Choke cherries (*Prunus virginiana* L.) are also being investigated as an important fruit species with commercial potential. There are currently about 5-10 processors of choke cherry products in the Canadian prairies. All processed choke cherries currently are wild-picked but some improvement work has been done and an improvement project is currently underway at Indian Head, Saskatchewan. Choke cherries have been used as a shelterbelt and wildlife species for many years in the prairies. It is a drought hardy species suitable throughout the prairies which serves multiple functions in a shelterbelt of preventing soil erosion, protecting wildlife and as a commercial fruit producer. The economics of commercial choke cherry production in a plantation setting would be similar to that of saskatoons but, based on current knowledge of it's growth and potential, it is expected that management requirements would be slightly less, yields would be higher and prices would be lower.

Other agroforestry species which also have potential for fruit production include highbush cranberry (*Viburnum trilobum* Marsh.), buffaloberry (*Shepherdia argentea* Nutt.) and sea-buckthorn (*Hippophae rhamnoides* L.).

Wood Products

Many shelterbelts on the prairies are fully mature and are in need of renovation or replacement. Some farmers are now giving thought to their renovation options and are considering harvesting wood from the shelterbelts to defray the costs. Merchantable lumber in 55-year old shelterbelts in southern Manitoba which consisted mainly of green ash (*Fraxinus pennsylvanica* Marsh.) and American elm (*Ulmus americana* L.) (Kort and Ashford, 1993). The green ash averaged 3211 board feet per half mile while American elm averaged 4953 board feet per half mile. Assuming $462/thousand board feet for ash and $400/thousand board feet for elm the average shelterbelt contained $3,464 worth of wood per half mile. Although such returns may not justify the costs of shelterbelt establishment, they represent a diversification opportunity for local owners of portable bandsaws. Shelterbelt wood has a special attraction for some woodworkers as it represents a renewable wood supply and so is seen as a more environmentally friendly than wood derived from rainforest, old growth forest or other threatened ecosystems. According to a Saskatchewan retailer of specialty hardwoods, there is an increase in the number of requests for Saskatchewan-grown wood (Dawson, 1994, pers. comm.)

Woodlot ownership and management is becoming an important issue for farmers throughout the forest fringe area of the prairies. Much of their private forest land contains poplar, spruce and pine. The economics of pulpwood in Saskatchewan are no more attractive now than two years ago since pulpwood supplies from crown land remain high and stumpage fees are low. This is what the private landowner has to compete against. Delivered poplar is worth $19/tonne ($80/MBF) while spruce and pine are worth $25/tonne ($100/MBF) (Fincati, 1994, pers.comm.). The picture is much brighter for sawlogs though as spruce is now worth $51/tonne ($200/MBF) delivered. This is about 50% or $16/tonne greater than the price 2 years ago. This is due to quality sawtimber becoming increasingly scarce in British Columbia sawmills and an increase in world prices. The technological improvements in small portable sawmills is now also making it attractive for landowners to do their own value added processing, increasing the price of a tonne of quality spruce from $51 to over $100/tonne ($400/MBF). Currently, several examples exist on the Canadian prairies of individuals who are operating successful businesses based on value-added processing of native hardwoods and softwoods.

Wildlife and Recreation

Wildlife plantations on the Canadian prairies now involve the planting of over a quarter of a million tree and shrub seedlings per year.

Schroeder et al (1992) established that shelterbelts in Kansas increased wildlife species diversity and populations. The suitability of shelterbelts as habitat increased as number of tree rows increased, as the number of tree species increased and as the shelterbelt height increased. Besides tree planting, the World Forestry Center (1990) gave detailed recommendations for managing woodlots in Oregon so that deer habitat could be maintained or improved while harvesting forest products from the land.

Wildlife based activities in Canada were estimated to contribute over $6 billion dollars to the Gross Domestic Product (Statistics Canada, 1992). Cable and Cook (1990) estimated that hunting in Kansas windbreaks contributed over $30 million to the economy of the state. Although the benefits of tree planting for wildlife habitat do not benefit landowners directly, hunting and other wildlife-related activities inject a great deal of revenue into communities and local businesses. Much of the work is done by volunteers while project costs are often funded by public or private sources.

Summary

Agroforestry spans a broad range of suitable practices on the prairies. This paper has demonstrated that many of these practices are economically attractive ways for farmers to diversify their income and, in some cases, present opportunities for small scale or large scale industry. Agroforestry also increases species diversity including songbirds, game mammals and game birds.

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Agroforestry Technology Needs Survey for the Western United States[1]

Joyce Y. Jacob-Mua[2]

Abstract — In March 1994, an Agroforestry Technology Needs Survey was created and disseminated among various natural resource professionals in 17 states, (5 Regions), west of the Missouri River. The survey was co-sponsored by the USDA Forest Service and the Soil Conservation Service. This survey was carried out to (1) identify current agroforestry practices, and (2) subsequently determine agroforestry technology needs within each region. For each practice considered, three catagories of technology needs were deduced, namely: Research Needs (R), Technology Transfer Needs (TT), and Education/Training Needs (ET). The top three practices among the 17 states were Wildlife Habitat (98.2%), Farmstead Windbreaks (93.8%), and Field Windbreaks (93.1%).

Most technological needs for Wildlife Habitat practices at all three R, TT, and ET levels were in the areas of Species Selection (53.5%) and Ecological Effects (55.2%), while Species Selection (60.8%) and Planning & Design (64.9%) were needed at the TT and ET levels. Farmstead Windbreak practice requirements were Economic Benefits (68.8%) for all three technology need catagories, while Species/Site Matching (65.6%) was needed for both TT and ET, and Tree Genetic Improvement (61.4%) was needed for R purposes. Field Windbreak practice needs included Economic Benefits (64.7%) at all three technology need catagories. On the other hand, there was also a demand for Tree Growth Improvement (60.1%), Species/Site Matching (65.7%), and Planning & Design (57.4%) at the R, TT, and ET levels, respectively. In general, R, TT, and ET technologies in Species Selection are most needed to enhance wildlife practices, while technologies at all three categories are needed to generate economic benefits with regards to field and farmstead windbreak practices.

Introduction

The Agroforestry Technology Needs survey was originally created by the Forest Service in order to determine agroforestry practices that are used westwide. Later, the survey was modified in order to determine the technology needs within those practices. The purpose of the survey was to assist with a research, technology transfer, and education/training needs workshop(s) which will help identify the needs of agroforestry or conservation forestry that should be addressed. The five regions include all states west of the Missouri River (as shown in Figure 1). The targeted survey respondants involved three levels of natural resource professionals: administrative, middle management, and technology assistance personnel. These three levels were targeted in order to get an honest assessment of what technology needs were truly needed.

The term "agroforestry" refers to: conservation trees and shrubs integrated into agricultural land use systems to provide tree products and at the same time enhance agricultural production, natural resource conservation, and human environments. Examples of conservation agroforestry

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[1]Paper presented at the Agroforestry and Sustainable Systems Symposium in Fort Collins, CO, (August 7-10, 1994).

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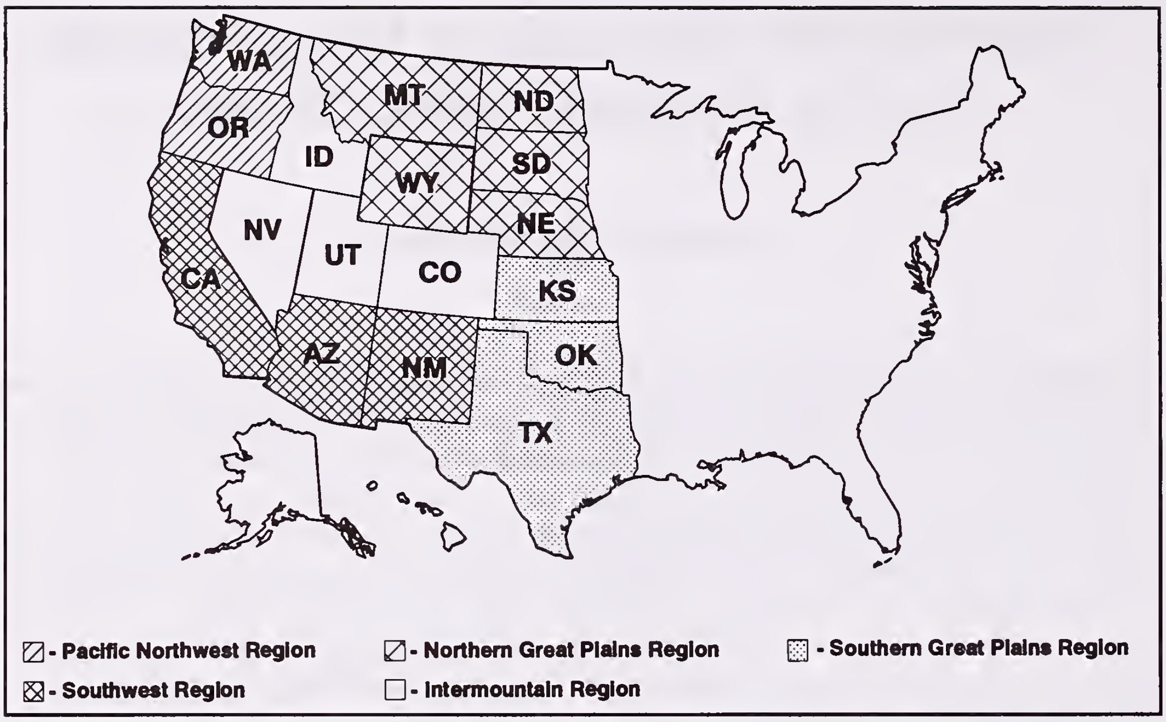

Figure 1 — States surveyed for agroforestry technology needs.

practices include: windbreaks to protect crops, farmsteads, and livestock; living snowfences to control snow drifting onto roads; and riparian buffer strips to filter contaminated runoff water. A complete listing of agroforestry practices is provided in the Appendix.

Research is defined as an activity whereby a problem is identified; a hypothesis formulated in order to direct how the problem should be tackled; objectives delineated to enable the hypothesis to be tested; an experimental study is then designed and conducted to provide data which is then statistically analyzed for its usefulness as information to solve the problem.

Technology Transfer involves identifying technology needs, then finding, interpreting, packaging, and providing information, tools, and guidelines to satisfy those needs. It includes: consultation, programs, workshops, conferences, and educational materials (brochures, posters, displays, handbooks, visual aids). Success is measured only when supplied technology produces results that meets or surpasses a targeted resource.

Acquiring education is the act or process of obtaining knowledge or skill in a particular field. Education/Training involves understanding the basic concept, design considerations, and appropriate applications for agroforestry and communicating that information to others in an understandable form.

Pacific Northwest

The top three practices used in the Pacific Northwest (PNW) are: riparian corridors and wildlife habitat (87.5%); and field windbreaks (62.5%). However, these three practices were ranked by priority as: field windbreaks (72%); riparian corridors (71.2%); and wildlife habitat (69.1%).

Within this region, the emphasis is placed more on the pasture plant than the trees. "Native" grasses for pasture are becoming increasingly popular. Utilizing native plants (shrubs, forbs, trees) for erosion control and revegetation projects is also receiving great emphasis.

Education (e.g., by Cooperative Extension) is found to be a primary need. More cost-share dollars are needed to encourage the implementation of various agroforestry practices. See Table 1.

Northern Great Plains

The top three practices used in the Northern Great Plains (NGP) are: farmstead windbreaks (97%); wildlife habitat (97%); and field windbreaks (94%). However, when ranked for priority, the top three practices are: farmstead windbreaks (81.7%); field windbreaks (79.6%); and livestock

windbreaks (72.3%). Although wildlife habitat was strongly used (97%), it was considered to be a medium priority (59.1%).

Survey responses from the NGP mentioned several times that renovation of existing windbreaks is needed. One respondant felt that planning and design considerations for snow management are sadly overlooked and omitted from training within his agency ...."Design considerations for snow management are so different from windbreak designs for wind management and energy conservation, that much more time and energy should be devoted to education efforts."

Clear-cut economic reasons to use trees and shrubs for field windbreaks must be available to landowners in order for them to adopt and implement this practice.

Apparently there is a strong wildlife habitat program in the NGP. Many hunters, along with those who simply enjoy viewing wildlife, are those who want to plant trees. See Table 2.

Table 1 - Pacific Northwest

Practices	% Used	% Priority Ranking
Field Windbreaks	62.5%	72%
Farmstead Windbreaks	50%	20.8%
Livestock Windbreaks	12.5%	25%
Living Snowfences	0%	0%
Filter Strips	37.5%	55.6%
Riparian Corridors	87.5%	71.2%
Wildlife Habitat	87.5%	69.1%
Alley Cropping	0%	0%
Wooded Pastures	62%	43.3%
Convert Mrg. Frmlnd	37.5%	41.7%

Table 2 - Northern Great Plains

Practices	% Used	% Priority Ranking
Field Windbreaks	94%	79.6%
Farmstead Windbreaks	97%	81.7%
Livestock Windbreaks	92%	72.3%
Living Snowfences	76%	32.1%
Filter Strips	58%	50.8%
Riparian Corridors	58%	60.5%
Wildlife Habitat	97%	59.1%
Alley Cropping	12%	3%
Wooded Pastures	30%	51.5%
Convert Mrg. Frmlnd	33%	45.1%

Table 3 - Southern Great Plains

Practices	% Used	% Priority Ranking
Field Windbreaks	91%	69%
Farmstead Windbreaks	100%	44.9%
Livestock Windbreaks	94%	63.4%
Living Snowfences	62%	51.3%
Filter Strips	54%	47.9%
Riparian Corridors	45%	69.4%
Wildlife Habitat	97%	60.7%
Alley Cropping	2.8%	10%
Wooded Pastures	22%	38.6%
Convert Mrg. Frmlnd	37%	30.6%

Southern Great Plains

Three top practices used in the Southern Great Plains (SGP) are: farmstead windbreaks (100%); wildlife habitat (97%); and livestock windbreaks (94%). However, the top three practices that are considered priority are: riparian corridors (69.4%); field windbreaks (69%); and livestock windbreaks (63.4%). It is interesting to note that although farmstead windbreaks had a strong showing as a widely used practice (100%), it was rated 7th priority-wise (44.9%). Wildlife Habitat was ranked 4th (60.7%), which puts it in the medium range.

Many of the comments from the SGP suggested that windbreak renovation needs are a real priority. Apparently, there is limited technical help available to plan and design windbreaks. As a result, many windbreaks are installed without the assistance of any cost-share programs.

Economics plays an important role in the selling of windbreaks to landowners. "The best way to sell windbreaks is by presenting accurate economic data. Farmers and ranchers may feel that the environment is important, but they are in business to make a profit," said one of the respondants.

This region also requested information on the protection of plantings from wildlife damage for the first few years of establishment. Information is needed on shelter, fencing, repellants, etc. See Table 3.

Southwest

Within the Southwest (SW), the top three practices used are: wildlife habitat (100%); field windbreaks (85%); and riparian corridors (78%). The top three priority rankings are as follows: wildlife habitat (73.2%); riparian corridors (72.4%); and wooded pastures (59.7%). Altough field windbreaks was highly practiced, it was only given a medium priority of 58.3%.

The SW had a low response rate to the survey. It is interesting to note that only one state within this region responded with comments, and the majority of the comments indicated that this particular state had little or no experience with many of the practices that were listed. Within this state, the primary use of trees and shrubs is to reduce salt in the soil, lower the water table, remove toxic salts, provide a useable wood product, and provide improvement in water quality. See Table 4.

Table 4 - Southwest

Practices	% Used	% Priority Ranking
Field Windbreaks	85%	58.3%
Farmstead Windbreaks	71%	57.1%
Livestock Windbreaks	28%	57.5%
Living Snowfences	14%	33.3%
Filter Strips	57%	47.5%
Riparian Corridors	78%	72.4%
Wildlife Habitat	100%	73.2%
Alley Cropping	14%	20%
Wooded Pastures	50%	59.7%
Convert Mrg. Frmlnd	42%	45.3%

Table 5 - Intermountain

Practices	% Used	% Priority Ranking
Field Windbreaks	100%	81.6%
Farmstead Windbreaks	100%	68.7%
Livestock Windbreaks	95.4%	59.8%
Living Snowfences	68.1%	55.3%
Filter Strips	59%	40.1%
Riparian Corridors	90.9%	60%
Wildlife Habitat	95.4%	54.2%
Alley Cropping	9%	30%
Wooded Pastures	13.6%	33.3%
Convert Mrg. Frmlnd	31.8%	17.8%

Intermountain

Five top practices are listed because there was a two-way tie between two practices. They are: field windbreaks and farmstead windbreaks (100%); livestock windbreaks and wildlife habitat (95.4%); and riparian corridors (90.9%). The top five practices considered as high priority are: field windbreaks (81.6%); farmstead windbreaks (68.7%); riparian corridors (60%); livestock windbreaks (59.8%); and living snowfences (55.3%). Although wildlife habitat is a highly used practice, it ranked sixth, (54.2%), as a medium-to-low priority.

The Intermountain (IM) region indicated a need for data to show local farmers that windbreaks will increase crop yields. Chemigation is a big problem that could harm tree plantings. Fast growing conifers and drought-hardy hardwoods are also needed for this region.

Economics is an important factor in the planting of livestock windbreaks. According to one respondant, "There are slow economic benefits to farmers to show why they should plant trees versus haybales or woodfences." This practice could also use research in the selection of various species in order to determine which species are tolerant of animal compaction, and which species are unpalatable to livestock.

Riparian Corridors within rangelands are an important issue, and more shrubs are being used within these corridors. The main question is what does one do to keep cows from damaging the riparian areas?

The IM region has experienced much controversy with the Fish & Game Agencies and the Wildlife Groups/Organizations in their view of using tall deciduous species for all-purpose windbreaks. See Table 5.

Westwide

The top three practices used Westwide are: wildlife habitat (98.2%); farmstead windbreaks (93.9%); and field windbreaks (93.1%). Even though these practices were highly ranked for their usefulness, it is interesting to note that farm-

stead windbreaks are considered first priority (78.6%), followed by field windbreaks (76.7%), and riparian corridors (69.4%). Although wildlife habitat is a strongly used practice, it ranked fifth, (61.1%), as a medium priority.

Overall, alley cropping is a practice that is not widely used (8.6%), and is considered to be a low priority (26%). The biggest concern with the use of alley cropping is the potential tree damage associated with the wide use of aerial applied herbicides. However, it was indicated that an increase in alley cropping research and demonstration efforts could attract more landowners to adopt this practice. Research on planting companion crops under established orchards and the most economically viable combinations are needed in order to place alley cropping as a high priority. See Table 6.

Westwide — Wildlife Habitat Needs

The top Research, Technology Transfer, and Education/Training needs for wildlife habitat are: species selection; species/site matching; planning & design; ecological effects; and conservation benefits. (Economic Benefits was not identified as a need within this practice). According to some of the comments, wildlife habitat is always encouraged as a secondary benefit in all types of windbreak plantings. Plantings with wildlife habitat as the primary purpose are just getting started with the assistance of Pheasants Forever. ASCS will not cost-share on weed barrier for wildlife tree plantings. However, weed barrier has been found to improve planting success, and it should be a component practice eligible for cost-share.

Table 6 - Westwide

Practices	% Used	% Priority Ranking
Field Windbreaks	93.1%	76.8%
Farmstead Windbreaks	93.9%	76.7%
Livestock Windbreaks	81.8%	69.4%
Living Snowfences	59.4%	66.2%
Filter Strips	56.8%	61.1%
Riparian Corridors	66.3%	59.7%
Wildlife Habitat	98.2%	56.3%
Alley Cropping	8.6%	56.2%
Wooded Pastures	30.1%	43.3%
Convert Mrg. Frmlnd	36.2%	26%

Table 7 - Westwide - Wildlife Habitat Needs

Practice	Research Needs	TT Needs	Education/Training Needs
S. Selection	53.5%	60.5%	68.4%
Tree G. Improv	32.4%	13.1%	10.5%
S/S Matching	51.7%	60.5%	60.5%
Plan. & Design	52.6%	63.1%	66.7%
Tree Establish	27.1%	29.8%	33.4%
Renov. Techs.	17.5%	19.2%	12.2%
Ecolog Effects	55.2%	58.7%	51.7%
T/C Interact	18.4%	19.2%	12.2%
Econ. Benefits	45.6%	48.2%	53.5%
Consv Benefits	51.7%	52.6%	65.7%
Pest Manage.	28.9%	22.8%	19.2%
Location	1%	0%	0%
Shrub Estab.[3]	1%	0%	0%
Animal Damage	0%	1%	1%

[1] S. Selection = Species Selection
Tree G. Improv = Tree Genetic Improvement
S/S Matching = Species/Site Matching
Plan. & Design = Planning & Design
Tree Establish = Tree Establishment
Renov. Techs. = Renovation Techniques
Ecolog Effects = Ecological Effects
T/C Interact = Tree/Crop Interactions
Econ. Benefits = Economic Benefits
Consv Benefits = Conservation Benefits
Pest Manage. = Pest Management
Tumblwd Manage = Tumbleweed Management
Chem Tolerance = Chemical Tolerance
Snow Manage. = Snow Management
[3] Shrub Estab = Shrub Establishment

Several respondants indicated a need for information on protecting plantings from wildlife damage for the first few years of habitat establishment. Many people were very concerned about wildlife, but they also felt a need to protect wildlife plantings in order to have an effective wildlife habitat area.

Respondants indicated that some of the benefits from wildlife habitat include: mast production of trees or shrub species that will grow in low rainfall areas; establishing trees on existing CRP grassland, (after the 10 year CRP program); studying species-specific habitat requirements; and recognizing wildlife pressures on habitats from establishment to maturity. See Table 7.

Westwide — Farmstead Windbreak Needs

Overall, the top agroforestry technology needs for farmstead windbreaks are: economic benefits; species selection; tree genetic improvement; species/site matching; planning & design; and pest management. Again, economic benefits was identified as the primary need for Research, Technology Transfer, and Education/Training.

According to some of the comments, it would be useful to look at all of the tree establishment technologies scientifically, both singly and in combination, to determine which ones work, and which ones don't. Although renovation techniques was not identified as a major need within farmstead windbreaks, one respondant stated that, "Renovation of older windbreaks, and economic benefits are real needs." Another respondant indicated that, "Training and education on better species selection in the design of new windbreaks is a real priority." There were a few respondants who felt that limited technical help was available to help plan and design windbreaks, and that many windbreaks were installed without the assistance of any cost-share programs. An increased variety of trees and shrubs that are suitable for planting on poor soils in low rainfall areas is also needed for all types of plantings. See Table 8.

Table 8 - Westwide - Farmstead Windbreak Needs

Practice	Research Needs	TT Needs	Education/Training Needs
S. Selection	52.2%	57.7%	62.3%
Tree G. Improv	61.4%	22%	11.9%
S/S Matching	47.7%	65.1%	66%
Plan. & Design	29.3%	62.3%	64.2%
Tree Establish	33.9%	52.2%	54.1%
Renov. Techs.	44.9%	52.2%	45.8%
Ecolog Effects	46.7%	33.9%	31.1%
Econ. Benefits	62.3%	69.7%	74.3%
Consv Benefits	32.1%	38.5%	47.7%
Pest Manage.	55.9%	35.7%	33.9%
Tumblwd Man.	1%	0%	0%
Wldlf Benefit[2]	1%	1%	1%
Snow Manage	1%	1%	1%
Aesthetics	0%	0%	1%

[1] S. Selection = Species Selection
Tree G. Improv = Tree Genetic Improvement
S/S Matching = Species/Site Matching
Plan. & Design = Planning & Design
Tree Establish = Tree Establishment
Renov. Techs. = Renovation Techniques
Ecolog Effects = Ecological Effects
T/C Interact = Tree/Crop Interactions
Econ. Benefits = Economic Benefits
Consv Benefits = Conservation Benefits
Pest Manage. = Pest Management
Tumblwd Manage = Tumbleweed Management
Chem Tolerance = Chemical Tolerance
Snow Manage. = Snow Management
[2] Wldlf Benefit = Wildlife Benefits

Westwide - Field Windbreak Needs

The top agroforestry technology needs for practices within field windbreaks are: economic benefits; species selection; tree genetic improvement; species/site matching; planning & design; and ecological effects. Economic Benefits was identified as the primary need for Research, Technology Transfer, and Education/Training. Several respondants stated that, "clearcut economic benefits are critical in selling this practice to landowners."

Apparently, the single-most prominent stumbling block is convincing landowners that planting windbreaks in their fields is beneficial to them. Education and incentives are major needs as evidenced by a respondant who stated that, "Field windbreaks is one of the most important practices, yet it rarely seems to occur. I perceive an educational and promotional problem." Technology and expertise are largely available, but there is limited adoption by agricultural producers.

Overall, the largest limiting factor for the establishment of windbreaks westwide is landowner education. Although there are many technical resources available, landowner education and the adoption of practices is the weak link. Economic cost for the establishment and benefits for the lifespan of windbreaks must be addressed in order for landowners to adopt these practices. Perhaps Cooperative Extension should take a more agressive, targeted role in agroforestry. See Table 9.

Appendix

Alley Cropping: Simultaneously growing a tree crop in widely spaced rows interspaced with an annual crop. The annual crop benefits from the protection of the trees and provides annual income while tree products provide income over the long term.

Agroforestry: Conservation trees and shrubs integrated into agricultural land use systems to provide tree products and at the same time enhance agricultural production, natural resource conservation, and human environments.

Farmstead Windbreaks: Rows of trees planted around the farmstead to provide wind protection, reduce heating and cooling costs, and improve aesthetics.

Field Windbreaks: Narrow rows of trees spaced at regular intervals in agricultural fields to minimize wind erosion and increase crop yields.

Filter Strips: Designed tree/shrub/grass buffer systems planted along streams and ditches to mitigate nonpoint source water pollution originating from adjacent uses.

Livestock Windbreaks: Rows of trees planted on the windward sides of livestock enclosures to provide wind chill protection, reduce feed costs and increase survival and weight gain.

Living Snow Fences: Rows of trees planted near roads to reduce dangerous cross winds, reduce snow drifting on roads and associated removal costs, and increase driving safety.

Riparian Areas: Streamside forests that buffer streams and rivers from adjacent land uses, reduce channel erosion, protect aquatic environments, and enhance wildlife and biodiversity.

Wildlife Habitat: Scattered or patterned plantings of trees, shrubs, grasses, and feedgrains to enhance wildlife.

Wooded Pastures: Also known as silvopastoral systems or livestock havens, they provide protection for livestock, increase forage production, and provide tree products.

Table 9 - Westwide - Field Windbreak Needs

Practice[1]	Research Needs	TT Needs	Education/Training Needs
S. Selection	45.3%	53.7%	52.8%
Tree G. Improv	60.1%	17.5%	8.3%
S/S Matching	38.8%	50%	65.7%
Plan. & Design	20.3%	57.4%	63.8%
Tree Establish	33.3%	51.8%	50.9%
Renov. Techs.	34.2%	43.5%	45.3%
Ecolog Effects	54.6%	32.4%	31.4%
T/C Interact.	53.7%	46.2%	35.1%
Econ. Benefits	62.9%	60.1%	71.2%
Consv Benefits	37%	40.7%	58.3%
Pest Manage.	45.3%	34.2%	27.7%
Tmblewd Man.	1%	0%	0%
Chem Tolerance	1%	0%	0%
Riparian	1%	0%	1%
Soils	1%	0%	1%
Snow Manage.	0%	1%	1%

1 S. Selection = Species Selection
Tree G. Improv = Tree Genetic Improvement
S/S Matching = Species/Site Matching
Plan. & Design = Planning & Design
Tree Establish = Tree Establishment
Renov. Techs. = Renovation Techniques
Ecolog Effects = Ecological Effects
T/C Interact = Tree/Crop Interactions
Econ. Benefits = Economic Benefits
Consv Benefits = Conservation Benefits
Pest Manage. = Pest Management
Tumblwd Manage = Tumbleweed Management
Chem Tolerance = Chemical Tolerance
Snow Manage. = Snow Management

Concurrent Workshop Summaries[1]

Abstract — Participants of the Agroforestry and Sustainable Systems Symposium were given an opportunity to attend one of three concurrent workshop sessions to discuss: (1) Research; (2) Technology Transfer; and (3) Education and Training, as they relate to agroforestry (AF). Each group was asked to identify, group and prioritize the needs and issues. The research group developed a list of research needs, methods, and topics. The technology transfer group developed a list of issues and concerns. From this list three priority needs/actions were identified: (1) landowner needs assessment; (2) grassroots/private sector marketing; and (3) demonstration programs/workshops. The education and training group categorized issues and needs into four areas: (1) general issues and concerns; (2) formal education; (3) community/youth education; and (4) continuing education/professional development.

Introduction

Having been primed with presentations on the current status of temperate, dryland agroforestry (individual practices, regional overviews, special topics, and barriers), symposium attendees were provided the opportunity of participating in one of three concurrent workshops held on the last day. The focus areas for the three workshops were: research, technology transfer, and education and training.

The groups were asked to identify, group, and prioritize needs and then suggest solutions and actions as time permitted. Each workshop group ended up with different products, but provided valuable input nevertheless.

The following is a compilation of the input gathered during the concurrent workshops of the Agroforestry and Sustainable Systems Symposium at Fort Collins, Colorado, August 10, 1994.

[1]*Workshops held at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

Workshop 1 — Agroforestry Research

Facilitated and Reported by:

- Michele Schoeneberger, USDA-FS, Rocky Mountain Forest and Range Experiment Station, National Agroforestry Center, Lincoln, NE 68583-0822
- Dick Schultz, Department of Forestry, Iowa State University, Ames, IA 50011

The research disciplines of the attendees were extremely diverse, ranging from forestry and range science to agronomy; trees, crops, and insects to dollars; and basic biology to socio-economic analysis: thus reflecting the multidisciplinary nature of agroforestry science. The group was charged with identifying technical knowledge gaps and the research areas needed to fill these gaps to successfully implement agroforestry as a viable land-use option. Given the diverse backgrounds of the participants, much of the workshop was spent developing a list of topic areas and trying to come to a consensus as to which of the topics were research needs ("what is needed?") and which were research methods ("how do we obtain the information?"). A condensed list was synthesized by Chuck Francis,

Director of the Center for Sustainable Agricultural Systems (University of Nebraska-Lincoln), and is presented below. In some cases, items appear in both lists since the need to develop appropriate methods for use in agroforestry research was considered by the group to be a "researchable" activity in itself. The entire unedited list has been presented at the end of this report. Please note that the order in which both lists are presented do not reflect any prioritization by the group.

Research Needs (What):

- Tree improvement/species selection
- Establishment & management of agroforestry plantings
- Waste product applications, nutrient cycling
- Landscape/farmscape/watershed design
- Value added/economic innovations
- Barriers to adoption/identification of customer needs
- Policy/federal & local program options
- Statistical designs and methods
- Decision support systems

Research Methods (How):

- Interdisciplinary teams
- Watershed-level focus of research
- Site specificity, study unit size, scale
- Long-term focus and methods
- Statistical designs and methods
- Valuation techniques for 'intangible" costs and benefits
- Funding for broad, long-term integrated research

Given the diversity of the group, and, more importantly, the wide array of technical knowledge gaps recognized by the group, the one-hour time period was not adequate to complete the charge assigned to this workshop. In trying to bring the group to a common perspective, Vashek Cervinka (California Department of Food & Agriculture, Sacramento, CA) went through his own research program as a case in point. He pointed out that we don't do agroforestry for the sake of agroforestry; rather we use agroforestry to address a problem. Given the specific needs and constraints imposed by a problem, identification of agroforestry research "NEEDS & METHODS" follows. For Cervinka, the problem was salinity. The research needed to test the feasibility of an agroforestry option to salinity-management was as follows:

1. Tree: plant/maintain/irrigate
2. Selection of trees (superior): how/clone propagation/test plots
3. Selection of halophytes: survey/field test/biological safety
4. Reuse of water by trees & halophytes
5. Solar Evaporation: salt crystallization
6. Biomass Use/Marketing
7. Uptake of Selenium by trees and halophytes
8. Agroforestry and wildlife interactions
9. Salt Use/Marketing

What became apparent from going through this exercise, and from the workshop as a whole, was that research needs in agroforestry can be defined within three broad levels: (1) development of the plant materials for agroforestry plantings (e.g. species and genotype selection, genetic improvement and propagation); (2) development of the agroforestry planting (e.g. design, establishment, and management); and (3) integration of the planting into sustainable land-use systems to attain desired goals (e.g. ecological, economic, and social considerations). There is obviously much information still needed in order for us to better understand the impacts of agroforestry plantings in the ecosystem and optimize the benefits of agroforestry. "Agroforestry is still emerging as a science but has been an art form in many parts of the world for centuries" (Vergera and MacDicken, 1990. Agroforestry: classification, and management. John Wiley & Sons, NY,NY).

List of Research Topics

- Site/Region specificity
- Watershed level

- Long-term studies
- Application specific
- Interdisciplinary (ecological/economic/social)
- Adoption barriers
- Include field professionals
- Economics
- Socioeconomic emphasis (customer needs)
- Value-added products
- Valuation studies (intangibles)
- Legal/Institutional policy
- Waste product application for alley cropping (Agroforestry Systems): municipal and agri cultural
- Agricultural effluent on fish production
- Integrate agroforestry into sustainable agriculture
- Systems statistics
- Tree improvement
- Species selection
- Landscape architecture in faunal communities
  - beneficial/detrimental
  - insects/fish/game & nongame species)
- Decision support models/tools
- Agroforestry under stress conditions
- Fast-growth timber
- Establishment practices
- Herbicide compatibility
- Silvicultural management/renovation
- Riparian practices on major floods
- Interagency funding/projects - focus funding
- Replicated across regions = COORDINATED RESEARCH
- Environmental remediation
- Wood quality related to agroforestry
- NPS pollution related to agroforestry

Workshop 2 — Agroforestry Technology Transfer

Facilitated and Reported by:

- Jerry Bratton, USDA-FS, Rocky Mountain Forest & Range Experiment Station, National Agroforestry Center, Lincoln, NE 68583-0822
- Lyn Townsend, USDA Natural Resource Conservation Service, Western National Technical Center, Portland, OR 97209

Table 1. Priority List for Agroforestry Technology Transfer Programs

Rank	TT Needs/Activity	Issues[1]
1	Landowner Needs Assessment	1, 21, 23
2	Grassroots/Private sector marketing	2, 5, 8, 22
3	Demonstration program/workshops	6, 13, 15
4a	Coordination of AF agencies and organizations	10, 20
4b	Top-down support (i.e. Farm bill); Technical support	3, 9, 19, 24
5a	Information materials and delivery	4, 17
5b	Turnkey programs12	
6	Technology exchange & training of AF professionals	11, 18
7	Need to reach "outsiders"	7
8	Directory of AF professionals	14
9	Technical assistance and project follow-up	16

[1] *Refer to Issues and Concerns listing (Numbers 1-24)*

Participants listed issues and concerns, and then grouped them into 11 broad categories (Table 1). Participants were asked to rank as priority 1, 2, or 3. Tallying the results, and dividing the total number of responses for each category by 3, resulted in the ranking of 1 to 9 (Table 1). Ranking 4 and 5 each have two categories. The top three priority needs/actions identified by the group are: 1) Landowner Needs Assessment; 2) Grassroots/Private Sector Marketing; and 3) Demonstration Programs/Workshops.

1. Landowner Needs Assessment: The participants felt a mechanism for landowner feedback with respect to their needs and concerns is missing. There is concern that we (professionals) may "push" our agenda on the landowner. Also, many felt that we're not getting the "message" of agroforestry (AF) out to the landowner sufficiently. Participants expressed knowing the needs of individual landowners (i.e. grassroots level) is important to understanding WHY they aren't adopting AF practices.
2. Grassroots/Private Sector Marketing: Participants felt a grassroots level push is needed to market AF. Current marketing strategies need to be enhanced and emphasized. Utilize innovative landowners to sell AF practices by showcasing how they have benefited from AF technology on their

property. The group suggested that private industry could be used to increase the visibility of AF through promotion and advertisement.

3. Demonstration Programs/Workshops: The group would like to see a wide-spread demonstration program initiated, with sites on both private and government owned land. Establishing demonstration sites that show appropriate technology applied to various land conditions will provide landowners the opportunity to see how they can adapt the AF practice to meet their particular needs. Workshops for training professionals has overwhelming support, because without training how can AF technology be transferred to landowners effectively.

Issues and Concerns:

(The order in which this list is presented does not reflect any prioritization by the group).

- Landowner feedback on: (1) needs and concerns; (2) attitude towards adoption of technology (we may "push" our agenda on landowner).
- Improved grassroots effort needed
- Need greater internal support, a "top-down" approach.
- Publications are available, but the delivery system to landowners needs to be improved.
- Needs to enhance marketing efforts at the grassroots level.
- Develop and promote a nationwide demonstration program located on both private and government owned land.
- We preach to the choir all too often, instead we need to reach "outsiders".
- We haven't thoroughly identified private sector "innovators", and utilized their ability to promote adoption of agroforestry technologies by others.
- Increased encouragement for resource professionals to actively promote agro-forestry to cooperators.
- Increased coordination/consistency between state and federal agencies with regards to technical information development and dissemination, and other technology transfer activities.
- Need better information exchange between resource professionals - especially at grassroots technical assistance level.
- There is a lack of turnkey programs for landowners (i.e. tree planting, maintenance, etc.).
- There is a lack of workshops for both professionals and non-professionals, to address localized agroforestry needs.
- Need a directory of agroforestry professionals, and make it accessible to other professionals and cooperators.
- Need to improve technology transfer delivery programs because the idea that "One size fits all" is not always the best approach and usable.
- Need to encourage resource professionals to do follow-up visits with cooperators to see how agroforestry technology is serving their specific needs.
- Need to develop a better "network" system to share current information such as an agro forestry bulletin board, regional newsletters and working groups, symposiums, trainings, etc.
- More agroforestry training needed for resource professionals.
- Need to get agroforestry in the 1995 Farm Bill.
- Need to develop strong cohesive regional coalitions.
- Need to evaluate our effectiveness to find out why agroforestry is not being adopted. Are we getting the "message" to the landowner?
- Lack of private business sector involvement similar to the Conservation Tillage Program thrust.
- Perform a "needs" assessment of individual landowners.
- Lack of tax, and other incentives for cooperators that adopt agroforestry practices.

Workshop 3 — Agroforestry Education and Training

Facilitated and Reported by:
- Dennis Lynch, Colorado State University
- Vern Quam, North Dakota Extension Service, North Dakota State University

The group categorized issues and needs into four areas: (1) general issues and concerns; (2) formal education; (3) community/youth education; and (4) continuing education / professional development. Materials generated were summarized and sent to participants for review.

General Issues and Concerns

- How do we get agroforestry into traditional forestry education programs?
- Are there more efficient ways to disseminate agroforestry information? - It is increasingly more difficult for people to travel to workshops because of time and expense problems.
- Can we develop regional cooperation in the use of agroforestry expertise and resources?
- Is it possible to improve networking between professionals interested and involved in agro forestry? - Using electronic bulletin boards, e-mail, etc.
- How should we be training agroforestry trainers?
- We need to focus on how people learn agro forestry practices rather than how people teach agroforestry.
- How can we reach teachers (while in college) with an accurate understanding of conservation which will, in turn, be used to more effectively reach youth with an accurate understanding of conservation issues and solutions?
- Can the interaction of the science cadre with research, teaching, and extension education be improved?
- How can interdisciplinary training and team work be improved?
- We need to review the interrelationship between private and public education institutions involved in agroforestry.
- How can we improve the involvement of practitioners (i.e. farmers, ranchers, producers, etc.) in agroforestry education programs?

Formal Education

The following were identified as they relate to Bachelors and Masters degree courses and programs in agroforestry.

- Integration of the various disciplines related to agroforestry. There is a need to integrate forestry with agriculture with horticulture with ecology with others, to produce agro forestry professionals who understand integrated systems.
- Development of a philosophy of intensive and extensive management of natural resource systems.
- Focus on ecological and physiological process and the results will follow rather than starting with a results only focus.
- Should viable agroforestry degrees be developed on a regional basis? Where would people with such degrees go in the job market? Is it feasible to offer a major in agro forestry or should agroforestry be an emphasis of an area of study?
- Increase basic and applied research in agro forestry to support educational programs in agroforestry.
- There should be stronger social science education emphasis to support formal educational programs in agroforestry.
- There is a need to identify professionals in agroforestry fields.
- Should Society of American Foresters (SAF) specifically accredit agroforestry programs?
- Agroforestry courses and programs should incorporate ecosystem management thinking.

Community and Youth Education

- The need to integrate agroforestry into existing environmental education programs such as PLT, Project Wild, Project Wet, etc.
- Agroforestry education materials for the above programs need to be developed.
- Teachers should be involved in the development of such materials.
- There is a need for a type of field trip experience which can be available and accessible for teachers use.
- There should be agroforestry models and demonstrations of plantings and field labs for schools.
- Agroforestry examples are needed that are readily exposed to the community.
- There should be integration of interdisciplinary fields.
- Other disciplines should be involved, such as soil scientists, hydrologists, landscape architects, wildlife biologists, etc.

Continuing Education / Professional Development

- This should be centered at the University level with input from the agencies and the SAF Agroforestry Working Group.
- Education needs to be expanded outside the regular university curricula to reach out to practicing agroforestry professionals.

Conclusion

Funding and support for agroforestry are currently limiting, yet the demand for the technology continues to increase. In order to meet this demand, coordination and collaboration among various agroforestry efforts are necessary. It is the hopes of the symposium organizers and sponsors that this will have, in part, been accomplished by these sessions.

Ecological Approach to Understanding Agricultural Systems[1]

David F. Bezdicek and Colette DePhelps[2]

Abstract — Although preliminary investigations have been undertaken, much remains to be learned about the magnitude and extent of agriculture's effect on natural systems, as well as the social, economic, and environmental consequences of alternative production systems. With ecologists combining their knowledge of natural ecosystems with agriculturalists knowledge of cropping systems, potential exists to devise ecological approaches to agricultural research and education. This ecological approach to agriculture is advocated by Soule and Piper in their book *Farming in Nature's Image.*

Sustainable Agriculture, Alternative Agriculture, and Best Management Practices

Sustainable agriculture is not a set of specified production practices, rather it is a goal and a continuing process. Sustainable agriculture is an approach to agricultural production that maintains ecosystem stability while conserving natural resources and providing for both the current and future generations. Although the topic of sustainable agriculture has been debated in the past, most proponents agree sustainable agricultural systems of food and fiber production support activities which are environmentally, socially, and economically viable.

Alternative agriculture "is the process of on-farm innovation that strives toward the goal of sustainable agriculture." Alternative farming systems deliberately integrate and maximize naturally occurring beneficial interactions. The objective of alternative systems is to sustain and enhance, rather than reduce and simplify, the many interactions upon which production agriculture depends. Management, biological relationships, and natural processes are emphasized. Alternative systems tend to be diversified and through this diversity, are thought to be more stable and resilient both ecologically and economically. Although there is much recent emphasis on below-ground biology, biodiversity, forest ecosystem health, and soil quality/health, there is a considerable basic knowledge gap in understanding these basic processes.

Alternative farming systems are comprised of management practices carefully adapted to the biological, physical, special conditions of the farm and region. Alternative farming practices often require more information, trained labor, time and management skills per unit of production than most conventional farming methods. Practices commonly proven to be the most effective in protecting the environment and economically viable are referred to as best management practices (BMPs). BMPs are essentially agronomic, managerial, or structural techniques that provide at least the minimum treatment needed to protect soil, water, and related plant and animal resources and solve water quality problems.

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[1] *Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2] *David F. Bezdicek is Director for the Center for Sustaining Agriculture and Natural Resources and Professor of Soils at Washington State University, Colette DePhelps is Outreach Coordinator for the Center for Sustaining Agriculture and Natural Resources at Washington State University, Pullman, WA 99164-6240.*

Marketing Agroforestry: Solving People's Problems and Meeting Needs[1]

Thomas J. Makowski[2]

Abstract — Successfully implementing government conservation programs is simply a matter of identifying people's needs and meeting those needs. However, while the concept may be simple, there is "a devil in the details." That is, it is not always so simple to find a way to meet those needs, address those concerns, or solve those problems through participation in a conservation program. However, with some effort, creativity, and a willingness to reject the traditional "business-as-usual" implementation strategies, conservation programs can be planned so participation is voluntary, amiable, and rapid.

This presentation, Marketing Agroforestry: Solving People's Problems and Meeting Needs, will provide listeners with a means for understanding landowners and managers that will enable them to develop implementation strategies to more effectively motivate people to establish and maintain agroforestry systems.

Specifically, the presentation will provide strategies for understanding: 1) why landowners and managers don't adopt agroforestry and sustainable systems; and 2) how to use principles from marketing to persuade landowners and managers to establish and maintain agroforestry systems.

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[1]*Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2]*Thomas J. Makowski is Environmental Sociologist, USDA Soil Conservation Service, 501 Felix, PO Box 6567, Fort Worth, TX 76115.*

Conservation Trees for Your Farm, Family & Future[1]

Mary Yager[2]

Abstract — Conservation Trees For Your Farm, Family & Future is a cooperative program of the National Arbor Day Foundation, the National Association of Conservation Districts, the National Association of State Foresters, and the USDA: Agriculture Research Service, Agricultural Stabilization and Conservation Service, Extension Service, Forest Service, and Soil Conservation Service.

The Objective of the program is to inform farm owners and operators of the benefits of the 12 Conservation Trees practices - riparian filter strips, trees for wildlife, field windbreaks, alley cropping, tree plantations, living snowfences, trees for livestock, farmstead windbreaks, woodlot management, specialty crops, trees for recreation areas, and multipurpose plantings - and to encourage them to utilize organizations for local technical assistance.

A variety of tools are available to market the practices: public service announcements for radio narrated by John Denver; a 32-page booklet describing the practices; reproduction proofs of the 12 practices for use in newsletters, newspapers and other publications; and an 80-slide program with script describing the benefits of conservation trees.

[1]*Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2]*Mary Yager is Director of Program Services for the National Arbor Day Foundation, 211 N. 12th Street, Lincoln, NE 68508.*

Opportunities for Agroforestry in the 1995 Farm Bill[1]

Dr. Louis A. Licht[2]

Abstract — The Conservation Reserve Program Started Land Conversion

This paper will discuss three alternative cropping and land management scenarios that achieve the original goals listed in the 1985 and 1990 Food Security Acts which authorized the Conservation Reserve Program (CRP). The CRP's listed objectives were to: 1) Reduce soil erosion from highly erodible cropland; 2) Protect long-term agricultural productivity; 3) Reduce sediment deposition in streams, ponds, reservoirs, and ditches; 4) Improve runoff water quality by reducing fertilizer and pesticide use; 5) Develop, diversify, and protect habitat to increase wildlife populations; 6) Curb production of surplus annually harvested commodities; and 7) Provide some needed income support for farmers caught in a major depression.

Between 1986 and 1992, farmers enrolled 35.4 million acres of land into CRP 10-year contracts. Nationally, over 21,000,000 acres are now planted to domestic grasses, almost 59.3% of the total program. There are 8,000,000 acres of native prairie plant species, 2,000,000 acres of wildlife plantings, and 700,000 acres of filter strips and windbreaks now installed. A disappointing 2,500,000 CRP acres were planted with trees, less than 7% of the CRP.

The USDA offered financial and technical assistance through the USDA-SCS and State Natural Resource Agencies for tree planting, including a five-year CRP contract extension for tree-planted acres. Yet, many farmers remained unconvinced that trees would offer sufficient return and flexibility when the contract expired.

Following the 10-year CRP contract, farmers can legally remove any and all of these plantings as long as they follow their filed conservation plan. A farmer can financially benefit by replanting the CRP acreage to corn, thereby adding land to a farm's corn base which increases a farm's value for loan collateral. Perennial grasses can be removed simply by the pass of a plow and herbicide application before a corn/soybean crop rotation is re-established. It is possible for the land to revert from perennial polycultures that reduce erosion to annually tilled, overproduced carbohydrate and protein commodities. Because of contouring and crop residue management, no-till corn/soybean rotations may leak less than fall moldboard plowing. However, farm managers cannot hope to hold the soil and a sustainable future with annually tilled row crops on highly erodible land, and the population downstream does not want the pollutants in the runoff.

In 1990, the Soil and Water Conservation Society surveyed 2,000 CRP contract holders. The average landowner was 57 years old, had a high-school education, owned and operated 323 acres, and produced less than 50 percent of the

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[1]Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).

[2]Louis A. Licht, Department of Civil and Environmental Engineering, University of Iowa, Iowa City, IA 52242.

household income by farming. CRP supported few new farmers, or few new rural industries. Arguably, the CRP supported even more absentee land ownership, took more land out of harvestable crop production, and did not provide a long-term stability to the erodible landscape.

The CRP wasn't productive for a strong rural farm economy. The value paid to the landowner was usually 30 to 40% of the income produced by the annual crop. Through this value may have equalled the profit of farming, it reduced the money that supported the farm-supported businesses in small towns.

This discussion will discuss the national goals of a vital agriculture, reduced water pollution, protection of indigenous wildlife species, and a secure renewable resource base for commerce. The 1995 Farm Bill affects all these topics. By building on the past 10 years of experience, can this legislation convince the professional farm manager to plant the buffers and terraces without the need for subsidy and additional regulation?

Forming the Idaho Agroforestry Coalition[1]

Thomas W. Christensen and Gary A. Kuhn[2]

Many activities led to the formation of the Idaho Agroforestry Coalition. Key activities included: SCS commitment to staff a state forester who would focus on windbreak technology transfer; windbreak technology training to multi-agency personnel; woody field trials by the Aberdeen SCS Plant Materials Center; using new windbreak designs and establishment methods; increasing the use of incentive programs; landowner workshops; creation of a statewide living snowfence program; and increasing the use of quality nursery stock.

The demand for windbreaks greatly increased after the first windbreak technology course held in Twin Falls, Idaho in 1992. (Another course was held at Pocatello, Idaho in 1994.) Participants took this information and transferred it to landowners through workshops and on-site assistance. The Idaho Forest Stewardship Program expanded the Stewardship Incentive Program to include windbreaks (SIP-4) in 1993. The demand for this practice was overwhelming, creating the need for increasing the priority for windbreaks in other cost-share programs, such as the Agricultural Conservation Program (ACP).

As the demand for windbreaks has grown, the need for quality nursery stock also increased. In response, the University of Idaho's Forest Nursery increased production of 20-cubic-inch seedlings (Styro-20s) to help meet the needs for agroforestry applications. The Plant Materials Center (PMC) at Aberdeen, Idaho also installed woody field trials that proved very useful for testing windbreak species suitability. The PMC also did some excellent work in riparian area restoration using willows.

All of these activities were helping to promote agroforestry, however, there was a need to achieve coordination between agencies and organizations. An initiative to form an Idaho Agroforestry Coalition was co-sponsored by the Idaho Association of Soil Conservation Districts and the Idaho Resource Conservation and Development Association Inc. The main objective; build partnerships for grassroots support of agroforestry practices to help landowners enhance their natural resources and sustain agricultural production.

The poster paper describes the Coalition's mission and main goals, lists the agencies and organizations that are participating, and describes the key activities that led to the Coalition's formation. It also displays key agroforestry demonstration projects that helped promote the use of agroforestry practices to meet resource needs and improve the quality of life.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2] *Thomas W. Christensen and Gary A. Kuhn, USDA Soil Conservation Service, 3244 Elder Street, Room 124, Boise, ID 83705.*

Stress Physiology Research at the Agroforestry Center[1]

Bert Cregg[2]

Environmental stresses such as drought, heat, and extreme cold limit the survival and growth of trees planted in conservation forestry systems. The goal of the stress physiology research program at the Agroforestry Center is to accelerate the selection of stress tolerant trees by:

- Identifying stress tolerant trees for agroforestry
- Increasing our understanding of the physiological bases of stress tolerance
- Improving propagation systems for hardy trees

In the Stress Physiology Research program at the Center we are identifying drought tolerant seed sources of important conservation tree species such as ponderosa pine, Scots pine, and green ash. Our research team is testing seedlings from diverse seed sources for survival and growth under controlled drought conditions. Our research is directed at understanding which mechanisms are most closely related to increased drought tolerance and may therefore serve as screening criteria for accelerated tree selection. In addition, we are conducting trials to improve nursery techniques to improve juniper germination as well as increase our understanding or seed dormancy in this important conservation tree. Researchers at the Agroforestry Center are also developing micro-propagation techniques for green ash in order to clone superior genotypes.

Partners for our research work include the University of Nebraska, the Intermountain Conservation Nursery Association, Oklahoma State University, the Center for Development of Hardy Landscape Plants, New Mexico State University, the International Arid Lands Consortium, and the Institute for Forest Genetics and Breeding (Voronezh, Russia).

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2]*Bert Cregg, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, National Agroforestry Center, East Campus-UNL, Lincoln, NE 68583-0822.*

Harvest Prediction of Muskmelon (*Cucumis melo* L.) Cv. Hiline Using Microclimate Parameters in Sheltered and Exposed Areas[1]

Entin Daningsih[2], Laurie Hodges[2], Donsheng Zhang[3], James R. Brandle[3], Susan L. Cuppett[4], Kenneth G. Hubbard[5], and Charles A. Francis[6]

Shelterbelts have been shown to improve growth and production of many crops through microclimate modification to the leeward of the shelterbelt. Field experiments were conducted to determine the microclimate effects of shelterbelts on harvest timing and total soluble solids of muskmelon fruits during the 1992 and 1993 growing seasons. The treatments were sheltered areas protected from the prevailing winds by mature conifer/hardwood shelterbelts and unprotected areas exposed to the prevailing winds.

Muskmelon plots in sheltered areas were located with 1 to 2H (H = height of the shelterbelt). Fruits were harvested at half to full slip three times per week for a total of 8 times in 1992 and 13 times in 1993. Total soluble solids of mature fruits were used as an indicator of muskmelon fruit quality.

Windspeed, wind direction, air temperature, relative humidity, and soil temperatures were measured continuously and both hourly and daily averages were recorded. Vapor pressure deficit was calculated from air temperature and humidity.

There were no significant differences in yield in 1992, but in 1993 marketable yield was significantly greater from the sheltered areas. Harvest timing in the sheltered areas was 5 to 7 days earlier than those in the exposed areas. Total soluble solids in the fruit, which indicate fruit quality, were not influenced by the wind protection. Air temperature and soil temperature were correlated with early plant development and faster growth.

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2]*Entin Daningsih and Laurie Hodges, Department of Horticulture, University of Nebraska-Lincoln, 373 Plant Science Building, Lincoln, NE 68583-0724;* [3]*Donsheng Zhang and James R. Brandle, Department of Forestry, Fisheries, and Wildlife, UNL;* [4]*Susan L. Cuppett, Department of Food Science and Technology, UNL;* [5]*Kenneth G. Hubbard, Department of Agricultural Meterology, UNL; and* [6]*Charles A. Francis, Department of Agronomy, UNL.*

Livestock Waste Vegetative Filter Project[1]

Richard L. Davis[2]

Kansas has a significant number of livestock operations not subject to the National Pollutant Discharge Elimination System (NPDES) permit program. Many of these livestock operations, including dairies, must have a state permit. Though many of these facilities are small, they have a potential water pollution problem due to uncontrolled runoff. Installation of a zero-discharge runoff-control system is one alternative for solving the pollution threat of these facilities. This livestock waste management approach often involves using an anaerobic lagoon, storage pit, or storage pond. Solid waste is usually separated from liquids and applied to cropland. Liquids may be either pumped, hauled, and applied to cropland, or used for irrigation. Handling the volume of liquid waste is labor intensive for small operations.

Research has indicated that vegetative filter strips are an alternative approach to treating livestock waste for operations and conductive site conditions. The principle drawback of these systems is the inability to control runoff from large storm events, which would circumvent the filtering process. Combining elements of zero-discharge and vegetative filter systems could eliminate uncontrolled runoff, while greatly reducing maintenance for operators.

The concept of this project is to provide a low maintenance livestock waste system that separates solid waste for convenient removal, provides sufficient detention time for liquid waste and runoff, and allows excess liquid to discharge into a vegetative filter strip designed for several management objectives. The site for this proposed project is a 200 head dairy operation in northwest Anderson County, Kansas. The owner primarily confines his livestock in an area with a concrete pad with structures enclosed on three sides and the roof. Despite scraping the pad daily, runoff associated with rainfall events occurs. The site contains natural swales that provide drainage through the site to the east property line, located approximately 1,350 feet from the confined area. The entire site has less than a five percent slope. Cattle are allowed to graze for short periods of time. The owner would like to provide shaded loafing areas for the cattle when they are grazing. Currently, the area contains only grass; woody vegetation is non-existent.

The design for this project involves the combination of a settling basin, storage pond, and vegetative filter strip. The design expectation is that the quality of any water discharging from the system will be equivalent to or better than runoff from adjacent land. The settling basin will trap the majority of solids, while the storage pond will provide approximately 180 days storage of liquids and runoff for controlled release. The filter strip will consist of grasses, wetland plants, and woody species composed of shrubs and trees. The size of the filter strip will be approximately 80' x 1,300' and follow the natural contour of the site. Grading to accommodate the filter strip should be minimal.

Besides filtering livestock waste, the filter strip will provide many additional benefits. Establishment of the filter strip will necessitate fencing out the cattle. By restricting cattle out of the filter strip, runoff from waste in grazing areas will be filtered before leaving the site. Fencing also provides the opportunity for rotational grazing to maintain quality pastures. The combination of grass, wetland plants, shrubs, and trees will provide a diversity of habitat for wildlife. The spatial configuration of the trees can also facilitate environmental design for livestock. Designed loafing areas will provide valuable shade in the summer and serve as a wind and snow screen in the winter. Summer breezes can be funneled into the loafing areas for additional benefit in the summer. Though a long-range consideration, timber production is also a possibility. Aesthtically, the filter strip will appear as a wooded draw to the casual passerby. Maintenance of the system will be minimal.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Windbreaks Save Energy and Money[1]

John Fusaro[2]

In the spring of 1969, Marv Strachan, former nursery manager for the Colorado State Forest Service, wanted to establish a windbreak around the site of his "to be constructed" home and property in Ft. Collins, Colorado. The purpose of the windbreak was to shelter his fields, protect his house, and improve aesthetics. He ended up achieving all of his goals with an added bonus of realizing a substantial energy savings.

The main portion of the windbreak, which borders the north and west sides of his property, consists of three rows: eastern red cedar, green ash, and ponderosa pine. On the southern edge of his property Marv planted a hedge row of cotoneaster. Hedgerows of cotoneaster, honeysuckle, and nanking cherry were planted within the windbreak.

The planting was irrigated by means of gravity flow through rows for the first ten years and has not been watered since. The water table is at a depth of 15 feet. Marv insists that a spray-irrigation-cultivation program is critical in achieving a successful windbreak. Tree rows were spaced so that a disk could be used to cultivate the soil. This cultivation controls weeds, improves soil tilth, and increases water and oxygen penetration into the soil. By maximizing the following six cultural practices Marv was able to get 1'-1 1/2' of annual growth of some of the ponderosa pine after 4-5 years.

- use of good plantable stock that is adapted to the area.
- irrigation.
- keeping the ground weed free (preferably by tilling).
- excluding livestock.
- watching for insects and disease.
- use of proper spacing when planting.

The benefits of the windbreak are numerous:

- controls snow drifting to acceptable locations.
- limits wind damage to the house.
- allows house paint to last longer, 19 years in this case.
- reduces energy costs.
- improves aesthetics.
- provides habitat for wildlife.
- reduces noise.
- limits evaporation from wind.
- increases field moisture.
- provides privacy.

A log of monthly gas use was kept and the figures showed a 40% reduction in gas consumption over a 20-year period (all variables remained the same except for the windbreak and the weather). This study showed that a windbreak's value can be measured both aesthetically and monetarily and its benefits far exceed the cost.

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Agroforestry Alley Cropping Project[1]

W. Geyer, B. Lamont, and C. Long[2]

Objective: Demonstrate costs and benefits incurred in converting a small area into a fine hardwood woodlot using the agroforestry alley cropping technique having annual income increments for a 15-year period, followed later with tree sales.

Justification: Kansas is not heavily wooded, but supplies a large amount of high quality hardwoods. Markets for walnut are established and additional sources are highly desirable.

The agroforestry alley cropping technique is one way to provide annual income until the trees are ready for harvest. Annual crops (agronomic/horticultural) grown in the alleys and short term woody plant (tree) crops grown in between high quality hardwood species in the rows will supply annual financial returns for many years early in the life span of the woodlot. Early financial income is typically lacking in woodlot establishment.

Clearly, an agroforestry alley cropping demonstration that shows economic benefits soon after tree planting could be of great importance to the farming/ranching community as it strives to include alternative crops into its standard agriculture operations.

Procedure: Establish ten (10) lines of 1:0 seedling trees at 40 feet between-row spacings each 300 feet long with black walnut trees planted in a single row 16 feet apart. Christmas tree species (scotch pine) will be planted in between each walnut tree. Three, six-foot wide weed control treatments are compared -- polypropylene weed barrier standard material, experimental weed barrier from same company, and a conventual herbicide (Surflan). Each will be 100 feet long and replicated once in each of the ten (10) lines of trees. Drip irrigation will be utilized in all treatments.

Agriculture/horticulture crops will be planted in the alleys. Plastic and drip irrigation will be utilized with 3 alleys planted to vegetable crops, 3 to a forage crop, and 3 additional planted to a grain crop. Actual crop rotation schemes to be determined and employed for at least 15 years of cropping.

Financial costs and returns: Evaluated at the first growing season for cultivated crops and expected to last for 15 years; Christmas tree products will be between years 5 and 12; firewood products after 20 years; walnut nut crop production from age 10 to 50; and fine hardwood logs at 50 years.

Final product: Fine hardwood woodlot with the potential to yield high quality sawlog/veneer logs along with early annual income attained through the alley cropping technique.

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2]*W. Geyer, B. Lamont, and C. Long, Kansas State University, Forestry & Recreational Resources, Throckmorton Hall East, Manhattan, KS 66506.*

The Windbreak Plantings at Chatfield Arboretum[1]

Chris Hartung[2]

During the last 10 years, 17,000 feet of multiple-row windbreaks have been planted on a high plains site in south Jefferson County, Colorado as part of the initial steps in developing a 350 acre Arboretum by the Denver Botanic Gardens. These windbreaks are intended to create microclimates for future plantings as well as to be used for educational programs emphasizing sustainability. Also, these windbreaks can provide valuable information regarding the performance of unique species which are continually being tried under various traditional windbreak cultivation strategies. Here is a list of windbreak species currently growing at the Chatfield Arboretum.

Abies concolor
Amelanchier alnifolia
Artemisia arbortanum
Artemisia tridentata
Caragana arborescens
Carpinus betulus
Catalpa speciosa
Ceanothus fendleri
Celtis occidentalis
Celtis reticulata
Cercocarpus montanus
Chamaebatiaria millefolium
Chilopsis linearis
Chrysothamnus nauseosus hololeucus
Cotoneaster acutifolia
Cowania mexicana
Crataegus ambigua
Crataegus mollis
Elaeagnus angustifolia
Fallugia paradoxa
Forestiera neomexicana
Fraxinus pennsylvanica
Fraxinus guadrangulata
Gledistsia triacanthos v. inermis
Gymnocladis diocus
Hippophae rhamnoides
Holodiscus dumosus
Juglans majoy
Juglans nigra
Juniperus monosperma
Juniperus osteosperma
Juniperus scopulorum
Juniperus virginiana
Lonicera tatarica
Maclura pomifera
Mohonia fremondi
Morus tatarica
Peraphyllum ramosissimum
Perovskia atriplicifolia
Picea pungens
Pinus albicaulis
Pinus aristata
Pinus banksiana
Pinus cernbra
Pinus edulis
Pinus engelmannii
Pinus flexilis
Pinus jeffreyl
Pinus koraiensis
Pinus leucodermis
Pinus nigra
Pinus peuce
Pinus peuce
Pinus Ponderosa
Pinus strobiformis
Pinus sylvestris
Pinus uncinata
Pinus washoensis
Populus deltoides
Prunus americana
Prunus rmeniaca 'mandshurica'
Prunus besseyi
Prunus fruiticosa
Prunus tornentosa
Prunus virginiana v. melanocarpa
Pseudotsuga menziesii
Ptelea trifoliata
Purshia tridentata
Quercus bicolor
Quercus douglasii
Quercus ellipsoides
Quercus gambelii
Quercus macrocarpa
Rhamnus smithii
Rhus trilobata
Ribes aureum
Robinia pseudoacacia
Rosa sps.
Sapindus drummondii
Shepherdia argentea
Syringa vulgaris
Ulmus parvifolia
Ulmus pumila

The Arboretum is open to the public seven days a week year around. For more information on the windbreak plantings contact Chris Hartung, Supervisor/Horticulturist, at (303) 973-3705, or write to Chris Hartung, Chatfield Arboretum, 8500 Deer Creek Canyon Road, Littleton, Colorado 80123-9430. The FAX number at the Arboretum is (303) 973-1979.

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2]*Chris Hartung, Chatfield Arboretum, Denver Botanic Gardens, 909 York Street, Denver, CO 80206-3799.*

Agroforestry Egypt: Sustainable Desert Development[1]

S.A.E Kandeel, Steven H. Sharrow, David Hibbs, and I. Kherallah[2]

A joint US-Egypt agroforestry research/development group is currently active under the US Agency for International Development-National Agricultural Research Program-New Initiatives Component project "Agroforestry techniques to ameliorate prevailing conditions in arid and saline parts of Egypt." This group includes researchers from the Departments of Forestry and Technology, Horticulture and Vegetable Crops, Soils and Water Science, and Plant Pathology at Alexandria University, the Agriculture Research Group of the Egypt Ministry of Agriculture, Tanta University, and the Colleges of Agriculture and Forestry at Oregon State University. *Agroforestry Egypt* began in 1991 to explore the potential of agroforestry to produce needed wood products, combat desertification, and increase farm income on recently reclaimed desert lands. It is a vertically integrated project which follows agroforestry woody biomass from production on small farms through harvest and processing into value-added wood products.

Final project data collection and analysis are still underway. Experiences to date suggest that:

1. Trees may be successfully established and grown both under irrigation *(Acacia cyanopylla, Casuarina glauca, Eucalyptus camaldulensis)* and in rainfed areas which receive more than 160-200 mm of annual rainfall *(A. cyanophylla)*.
2. Intercropping of young trees with vegetable crops may increase total farmer income by 9% the first year and 45% the second year after tree planting compared to vegetable crops alone. The combination of Okra and Acacia (with prunings sold for decorative greenery in resort areas) appears to be especially promising.
3. Intercropping Acacia trees with rainfed cereal crops may increase grain yields as well as provide a source of green feed for livestock. This is an emerging technology with high social acceptability in the north mediterranean coastal strip where livestock are especially important to local people.
4. Agroforestry woody biomass is suitable for use in industrial wood products. Properties of medium density fiberboard produced in project laboratories are superior to those of traditional particle board.

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2]*S.A.E. Kandeel, Steven H. Sharrow, David Hibbs, and I. Kherallah, Faculty of Agriculture, Alexandria University, Alexandria, Egypt; and Departments of Rangeland Resources and Forest Science, Oregon State University, Corvallis, OR.*

Agroforestry Systems: Salinity Control Management Option[1]

Fawzi Karajeh[2], Paryohay Davidoff[3], and Kenneth Tanji[4]

The potential environmental effect and a lack of an active regional drainage system are placing at risk the agricultural production of about 80 percent of the 2.2 million irrigated acres in the westside of California's San Joaquin Valley. Agroforestry systems are being investigated as a drainage management option. The subsurface drainage waters containing an average of 8000 mg/l TDS, 12 mg/l boron and 400 ug/l selenium are used to irrigate the eucalyptus plantation, and its evapoconcentrated drainage waters, in turn, are used on Atriplex, very salt tolerant shrubs. While this approach seems promising for the short-term, the long-term efficacy is not known yet.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2] *Fawzi Karajeh, Water Conservation Office, California Department of Water Resources, 1020 9th Street, Sacramento, CA 95814,* [3] *Paryohay Davidoff, California Department of Water Resources, and* [4] *Kenneth Tanji, University of California, Davis.*

Miller Creek Agroforestry Project[1]

James Lemmerman[2]

This project centers on a brook trout stream that runs through the cities of Duluth and Hermantown in northeastern Minnesota. The stream passes through rough forest land, highly developed urban land, and city park land. The county soil and water conservation district (SWCD) and citizen volunteers are using agroforestry (willow post planting) to moderate stream temperatures and reduce streambank erosion.

Planting occurred in May 1994, with a goal to increase shading and stabilize the streambank. The project was initiated by the SWCD, in cooperation with the Soil Conservation Service (SCS); Together Reach Out Upgrade Trout (TROUT), a local sports group; the Minnesota Board of Water and Soil Resources (BWSR); and the Minnesota Department of Natural Resources.

The 900 foot section of stream chosen for the planting is located between a large commercial parking lot and US Highway 53 and has very limited shading. Volunteers cut willow (Salix nigra) posts from stock growing within a few miles of the site. Posts were transported and planted the same day. As of August 1994, there appears to be 75 percent survival.

Background: Miller Creek is located in the cities of Duluth and Hermantown, Minnesota, at the western end of Lake Superior. Combined population is approximately 100,000. Miller Creek is a designated and viable brook trout stream (Minnesota Department of Natural Resources). The creek is 9.5 miles long and drains 6,304 acres (9.9 square miles). The creek rises in a wetland north of Hermantown and flows south through Duluth, into the St. Louis Bay. The last quarter mile of the stream flows through a tunnel under city streets and Interstate Highway 35, before entering St. Louis Bay and Lake Superior.

In 1973, land use in the Miller Creek watershed was estimated at 32 percent residential/suburban, 23 percent forestland, 21 percent commercial/industrial, 21 percent farm/open land, and 3 percent rock slope. From 1973 to present, the commercial and residential development has increased drastically, reducing the acres of open area and forest land.

Most residential development has occurred in the lower half of the watershed, whereas the commercial development has occurred in the middle of the watershed, just upstream of the primary trout habitat.

Fisheries Concerns: Miller Creek has a naturally reproducing brook trout population. The stream has a higher average number of brook trout than most other streams located in Duluth.

Water temperatures have been measured as high as 720 F, which is the upper limit for a brook trout stream. Water temperature is influenced by runoff from commercial development areas, lack of adequate streambank shade, and increased sediment loading. Because the highest concentration of development is upstream from the largest trout population, there is a higher potential for degradation.

* Technical information was taken from the Appendix of Stage I Project, St. Louis River Remedial Action Plan; Minnesota Pollution Control Agency.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2] *James Lemmerman, Minnesota Board of Water and Soil Resources, 394 South Lake Avenue, Room 403, Duluth, MN 55802.*

Tip Moth *(Rhyacionia spp.)* Infestation in Ten Sources of Ponderosa Pine *(Pinus ponderosa)* from Nebraska and South Dakota[1]

William R. Lovett[2], Mark O. Harrell[2], Mary Ellen Dix[3], and Laurie J. Stepanek[2]

Ponderosa pine *(Pinus ponderosa)* is a widely used species in windbreaks throughout the Great Plains. Recommended sources of ponderosa pine seed include Valentine and Ainsworth, Nebraska, and the Rosebud Reservation in South Dakota. These sources had good survival and growth in a ten year study by Read (Read, R.A. 1983. Ten-year performance of ponderosa pine provenances in the Great Plains of North America. USDA Forest Service Rocky Mountain Research Station, Res. Paper RM- 250). However, information on the susceptibility of these sources to the Nantucket pine tip moth *(Rhyacionia frustrana)* and the western pine tip moth *(R. bushnelli)* is limited. Tip moth larvae feed within the buds and shoots, causing trees to become stunted and deformed.

In this study one hundred half-sib families of ponderosa pine from ten geographic sources in Nebraska and South Dakota were evaluated in a plantation near Mead, Nebraska, over a three-year period for susceptibility to pine tip moths. Height growth of the trees was measured also.

Significant differences in tip moth infestation were found among sources and among families within sources. Sources located near Ainsworth, Springview, and Bassett, Nebraska, showed significantly lower infestation levels than the remaining seven sources. Families from the Rosebud Reservation and from Crookston and the Merritt Reservoir in Nebraska showed the highest overall infestation levels. The remaining sources, Valentine, Sparks, Kilgore, and Nenzel, Nebraska, showed intermediate infestation levels.

Of the top twenty-five families with low infestation levels, six (24%) were from the Ainsworth location, six were from the Springview location, four each were from Sparks and Valentine, and three were Bassett families. Nenzel and Kilgore sources each had one family in the top twenty-five resistant families (see table below). Mean infestation levels among all 100 families ranged from 23 percent of tips infested to 59 percent. A significant negative correlation was found between tip moth infestation and height growth.

Information from this study will be used when thinning the progeny plantation at Mead, Nebraska, to produce a superior ponderosa pine seed orchard.

Source	Total Number of Families	Number of Families in Top Twenty-Five
Ainsworth	7	6
Springview	10	6
Sparks	10	4
Valentine	10	4
Bassett	5	3
Nenzel	7	1
Kilgore	5	1
Crookston	4	0
Merritt Reservoir	6	0
Rosebud	36	0
Total	**100**	**25**

[1]Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).

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Pergularia daemia: A Shrub of Great Agroforestry Potential Used in Traditional Agricultural Practices in the Seno Zone of Mali[1]

S. Mahotiere[2], M.A. Kadri[3], Youssouf Cisse[4], and C. Kamissoko[3]

Key words:

- *Pergularia daemia*, soil chemical properties
- *Pennisetum glaucum*, grain yield

Pergularia daemia is a perennial and deep-rooted shrub traditionally preserved in fields in the semi-arid zones of the Seno plains of Mail for its soil-improving properties. According to the farmers, pearl millet *(Pennisetum glaucum)* plants grown in the vicinity of this shrub exhibit better growth and development, and produce more grain yield than the other plants. Independent and frequent observations in the peasant fields during two consecutive growing seasons (1992-1994) lent credence to this statement. This empirical information and evidence inspired a follow-up study designed to determine the effects of this shrub on soil chemical properties and pearl millet yield. At the grain filling state of the pearl millet, eleven (11) shrubs of an average canopy diameter of 1.3 m + 0.06 were selected. At 30 cm from the base of each shrub, soil samples were collected at depths of 0-15 and 15-30 cm for chemical analysis. The same procedure was repeated at 5 m away from the shrub (control). A quadrant of four square meter (4 m2) was delineated around the shrub and the pearl millet hills inside were counted. The same operation was performed at 5 meter away (control) from the shrub. The H2O and Kcl pH, available and exchangeable K, available P, and CEC significantly increased at 0-15 cm. But only Kcl pH significantly increased at 15-30 cm. Contrary to organic carbon, which decreased at this depth, available P and K, and exchangeable K increased. CEC showed no change. Grain weight, head weight, and length significantly increased in the vicinity of the shrub but the number of heads-per-hill was not affected.

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[1]Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).

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Measuring the Socio-Economic Impacts of Agroforestry Projects in the Philippines[1]

Evan Mercer[2], Belita Vega[3], Hermie Francisco[4], and Robin Maille[5]

Conventional wisdom suggests that agroforestry projects can provide both ecological and economic benefits. Most agroforestry project evaluations, however, have failed to adequately assess the socio-economic impacts. For example, a review of 108 agroforestry project impact evaluations by Sara Scherr of IFPRI reported that only 8% assessed economic costs or benefits, 5% examined adoption or distribution of benefits by type of participant, and less than a third assessed impacts on yields. This results from a number of factors including the lack of farm level input and output data, standardized methods for basic tree and crop yield assessments, and guidelines for data collection and analysis. Given this background, the Southeastern Forest Experiment Station and the USDA/USAID Forestry Support Program are cooperating to develop and test data collection and analysis methods for assessing the socio-economic impacts of agroforestry projects.

This poster paper presents an overview of the impact assessment methodology and some preliminary results from the first case study initiated on the island of Leyte, Eastern Visayas, Philippines in July 1993. The impact assessment process proceeds in three stages: l) an initial three- to four-week rapid appraisal; 2) a 9-12 month intensive data collection effort; and 3) data analysis. For the Philippines case study, stages one and two were completed in July 1994 with data analysis expected by October 1994. In the formal survey of 300 households, both male and female heads of household were interviewed to collect data on agroforestry adoption, production, non-market valuation, household time allocation, social, economic, and demographic information. In addition, a subsample of 37 households (both agroforestry adopters and nonadopters) were interviewed weekly for one year to gather in-depth farm budget/production, crop calendar, land-use calendar, household time allocation, and farm input and output data.

Production function analysis is used to estimate yields for annual and woody crop components of the farming systems. These are combined with market prices (and/or non-market valuations) of inputs and outputs in a spreadsheet format to calculate net present values of the agroforestry (with project) and non-agroforestry (without project) systems. The difference between these two values represents the productivity impacts at the household level. These analyses are referred to as household financial and household economic benefit-cost analyses. The household financial analyses calculate the monetary profitability of the farming system and provide insight into the cash income impacts of the project. Adding non-market inputs and outputs to calculate the total net economic benefits to the household provides the household economic analyses. Community level impacts are estimated by aggregating the household level analyses and using shadow pricing to estimate social values for inputs and outputs, including any externalities. The social equity/income distribution impacts are also evaluated at three levels. An intra-household analysis emphasizes the distribution of benefits and costs between sexes and generations within households. The inter-household analysis estimates the distribution between households at different socio-economic levels, while the inter-community level examines the distribution of benefits and costs between organizations.

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Casuarina in California[1]

Miles L. Merwin[2]

The genus *Casuarina* includes several evergreen tree species native to Australia which are widely planted for windbreaks, fuelwood, and erosion control. Farmers in California are planting windbreaks of casuarina to protect high value orchard, vineyard, and vegetable crops.

Casuarina has several characteristics that make it useful for field windbreaks. It is fast-growing, commonly exceeding 6 feet of growth per year. The foliage is wind-firm yet permeable. Casuarina normally retains its lower branches for ground level wind protection, and also can be sidetrimmed. Compared to other commonly used windbreak trees in California such as blue gum *(Eucalyptus globulus)* or athel *(Tamarix aphylla)*, casuarina does not compete unduly with adjacent crops or create debris problems from blowing leaves or bark.

Beefwood *(C. cunninghamiana)* is the principal species of casuarina planted for windbreaks in California. It commonly grows to a height of 75 feet and is hardy to about 18oF. Farmers plant beefwood windbreaks to improve the yield and quality of high-value, wind-sensitive crops such as wine grapes, kiwi fruit, and vegetables. Swamp oak *(C. glauca)* grows to about 50 foot tall and tolerates saline, waterlogged soil conditions better than beefwood. However, its relative frost sensitivity restricts its use to coastal or low desert valleys of California. Although not widely planted, Western Australia swamp oak *(C. obesa)* appears promising for planting on salt-affected sites where frost is also a potential hazard.

Research started in 1987 by the Casuarina Improvement Association, a cooperative effort by private growers, companies and public agencies, has focused on selection of the best Australian seed provenances for Califomia conditions. On the basis of extensive field trials of beefwood, seed sources have been selected for both rapid growth and frost tolerance. Work is underway to vegetatively propagate the best individual trees for the establishment of a clonal seed orchard. Provenances of *C. glauca* and C *obesa* have also been field tested by Casuarina Improvement Association cooperators.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Integrated Management of a Forest-Pasture System for Timber and Cattle Production[1]

P. Negresos-Castillo, F. Rivas-Pantoja, and L. Ortega-Reyes[2]

There are 246,000 hectares of deciduous woodlands in the north-central part of the Yucatan Peninsula. Presently, one of the major economic activities associated with the woodlands is cattle production. There are about 100,000 head of cattle being grazed in these woodlands. As it is presently practiced, grazing requires large areas of land from which the forest has been cleared and burned. After the land is grazed for a few years, it is abandoned and eventually revegetates to a low value, scrub forest. A few individuals graze their cattle in the forest, which is not nearly as harmful to the forests as clearing and burning. There is, however, a lack of knowledge about forest management for this purpose, many of the species in the forest are deciduous and shed their leaves during the dry season. All this results in little available forage for the cattle and low livestock production levels, which reinforces the practice of converting the forest to pasture. A project was initiated to help individuals who graze their cattle in the forest develop an ecologically sound system that would meet their needs for forage during the whole year, plus other products. In the system a portion of the woodland vegetation will not be grazed but will be used to produce natural forage for future years. This portion also will be enriched with high valuable timber species (e.g., *Cedrela odorate*) over time. Other portion of the land will be used to produce forage by planting forage plants. Highly productive species, like tropical grasses *(Andropogan gayanus)*; evergreen trees (forage trees such as *Brosimun alicastrum* and *Leucaena leucocefala)*; and shrubs, gradually will be added in this portion. All of the components of the system (natural forage in enriched forest, forage tree plantation, and pasture land) will be managed in space and time to provide the forage needed by the cattle during all seasons, to protect the planted trees during their first three years of life, to maintain forest diversity, and to create a sustainable production and income. This report highlights the most important aspects of the project development; describes the system, before the modification, in terms of its composition, productivity, and economic characteristics; describes the system modifications and management plan and the results after one year of establishment. The project will last for 15 years, and the three first years are being financed by PROAFT (Forestry Action Plan of Mexico).

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Pine Establishment and Competition Control in Fescue and Bermudagrass Pastures[1]

Henry A. Pearson[2]

Agroforestry systems research at the South Central Family Farm Research Center in western Arkansas, was established to develop guidelines for pine reforestation in improved pastures of the Central Highlands. The objective of this study was to determine the effectiveness of various methods of controlling vegetation competition on tree survival and height growth of southern pines in fescue *(Festuca arundinacea)* and bermudagrass *(Cynodon dactylon)* pastures. Shortleaf *(Pinus echinata)*, loblolly *(P. taeda)*, and longleaf *(P. palustris)* pines (0-1 seedlings) were hand planted in early March 1992 in fescue, fescue-legume (alfagraze *Medicago sativa*), and bermudagrass pasture types at spacings of 1.2 m within rows and 4.9 m between rows. Due to establishment failure of the alfagraze within the fescue sod, that pasture area was converted to subterranean clover *(Trifolium subterraneum)* in October 1992. Four vegetation competition control treatments were applied to the pasture forages: 1) control (no competition control); 2) herbicide (Oust in fescue and Fusilade 2000 in bermudagrass applied in April-May 1992 and 1993); 3) mulch (mow and mulched with grass hay or pine needles in April-June 1992 and 1993); and 4) cultivate (multivate, cultivate, or rototill March-August 1992 and 1993). Pasture grasses (with 336 kg/ha 13-13-13 N-PK, fescue in March and bermudagrass in May) and subterranean clover (with 224 kg/ha 0-24-24 N-P-K in March) were fertilized annually for hay production. The experimental design was a randomized block, where pasture types were randomized within replications, pine species randomized within pasture types, and competition control treatments randomized within pine species. During 1992, forage yields on unmowed areas were 6113 kg/ha in fescue pastures, 7041 kg/ha in the fescue-legume pastures, and 7009 kg/ha in the bermudagrass pastures. In 1993, one-time hay harvests in June and July yielded 3777 kg/ha in the fescue pastures and 2638 kg/ha in the bermudagrass pastures, respectively. Overall pine survival was 87.6% in June 1992, 71.6% in December 1992, 68.6% in June 1993, and 64.9% in December 1993. Pine survival during summer 1992 was not different either among competition control practices (varying from 84.6% to 91.2%) or pasture types (varying from 86.9% to 88.8%). However, survival was different among pine species during the first summer; loblolly (89.6%) and shortleaf (94.7%) pine survivals were higher than longleaf pine (78.6%). After two years, pine survivals and heights were not different among pasture types and averaged 64.9% and 63.1 cm, respectively. Loblolly and shortleaf pine survivals were still higher (81.7%) than longleaf pine (31.4%). All three pine species differed in height after two years (loblolly pine 102.6 cm, shortleaf pine 81.6 cm, and longleaf pine 5.1 cm). Survival and height of the pines with the various competition control treatments also differed after two years. Pine survivals were 51.3%, 61.4%, 70.0%, and 77.1% and pine heights were 36.8 cm, 59.6 cm, 70.2 cm, and 85.8 cm for the control, mulch, herbicide, and cultivate treatments, respectively.

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[1]Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).

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Status of Woody Plant Selection at the Manhattan Plant Materials Center[1]

John M. Row and Richard L. Wynia[2]

Evaluation or current status of the following species are summarized:

Thirty-two *Celtis occidentalis* accessions were established in 1981 plantings at Manhattan and Tribune, Kansas. A second common hackberry planting was established at Manhattan in 1988 consisting of 26 selected seedlings from accessions collected south of the Platte River in Nebraska.

Fraxinus pennsylvanica, green ash, plantings were initiated in 1961 at four Great Plains locations. Additional plantings, made in 1971, involved 14 provenances that included other species of ash. A provenance from Butler Co., Kansas (9004302) was judged to be superior at Horning State Farm near Plattsmouth, Nebraska and Manhattan, Kansas. Potential seed orchards were identified in 1993.

Fourteen Cotoneaster species were established at Manhattan in 1983. *C. lucids*, accession 325270, was selected and advanced to the next level of evaluation.

Sixteen accessions of *Ulmus parvifolia,* lace-bark elm, were established at Quinter and Manhattan, Kansas in 1982. The Quinter site has received severe deer browse and canker type diseases were observed at Manhattan.

Twenty *Ribes odoratum* accessions were established in 1988. Selections in the buffalo currant are scheduled to be made in late 1994.

Four accessions of sycamore, *Platanus occidentalis,* were established in 1985. The germplasm was obtained from Dr. Walt Bagley's anthracnose resistant lines. Excellent performance has been observed at Manhattan and a selection is anticipated.

Thuja orientalis, oriental arborvitae, plantings were established in 1983 at Manhattan, Kansas and Woodward, Oklahoma. Initially 40 accessions were established at Manhattan, but losses due to winter injury and disease have reduced the number to 30.

A *Quercus macrocarpa,* bur oak, trial was established in Manhattan during the fall of 1992 and spring of 1993. Twenty-six accessions from the upper Midwest were arranged in two plant, five replicate, randomized plots.

An assembly of *Salix exigua* interior was initiated in 1994. The collection yielded 30 accessions mostly of Kansas origin.

Selection of *Prunus americana,* American plum, and *P. angustifolia,* Chickasaw plum, were made in 1986. Breeders blocks of the two species were established in 1987 and the first stock destined for field planting was shipped in 1990.

The Manhattan Plant Materials Center is responsible for three woody releases to date, 'Pink Lady' winterberry euonymus, *Euonymus bungeanus*, 1973, 'Konza' aromatic sumac, *Rhus aromatica* var. sexotina, 1980, and 'Lippert' bur oak, *Q. macrocarpa*, 1994.

Releases of *F. pennsylvanica*, *Betula nigra*, and *P. occidentalis* are anticipated in the future.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Mountain Home Air Force Base Woody Inter-Center Strain Trial[1]

Loren St. John[2]

The purpose of the Mountain Home Woody Inter-Center Strain Trial is to identify and evaluate trees and shrubs for use in windbreaks and shelterbelts in the Snake River Plains (MLRA 11) of the Northwestern Wheat and Range region of the Intermountain United States. The site also provides a testing area for woody plant materials being evaluated by the Aberdeen Plant Materials Center for possible future release.

The site is located at the Mountain Home Air Force Base and the project was implemented through a Memorandum of Understanding between the Soil Conservation Service and the United States Air Force.

The test site is located approximately 10 miles southwest of Mountain Home, Idaho on a Bahem silt loam, 04% slopes. This soil is well drained with moderate permeability, high available water capacity, and potential rooting depth of 60 inches or more. The average annual precipitation is approximately eight inches, average annual air temperature approximately 500F and the frost free season is about 130 days. The typical soil profile is alkaline (pH 7.4-8.4) and salinity <2mmhos per cm. The windbreak suitability group is 8. The dominant vegetation in the potential natural plant community includes Wyoming sagebrush and Thurber's needlegrass. The elevation is approximately 3,000 feet.

There are 30 planting rows which are 276 feet long. Plantings have been made in 1991, 1992, and 1993. Between row spacing is 16 feet and within row spacing is dependent upon growth forms of the woody material planted in the row. Low growing shrubs are planted at three foot spacing, medium height shrubs 6-8 feet, and trees 8-10 feet. Accessions being tested for possible future release are replicated five times. Each plot consists of four individual plants. Accessions planted for display purposes are not replicated. The site is irrigated with a drip system and is fenced to exclude large animals.

The plants are evaluated twice each year, in the spring and in the fall. Evaluation data collected includes survival, vigor, plant height, leader length, and uniformity. Vigor and uniformity are subjective ratings based on a scale of 1-9 with 1 best and 9 dead or worst. Uniformity is based upon consistent height, branching pattern, and stem density which are important characteristics for plant materials used in windbreaks.

The 1991 planting had 79.5% survival at the end of the first growing season. At the end of the second growing season (1992) survival had increased to 84.7% and at the end of the third growing season (1993) survival was 84.4%. Overall vigor for the 1991 planting ranged from 3.1 (fall, 1993) to 4.5 (spring, 1992). Overall uniformity was rated as 3.8 for the 1991 planting by the end of the third growing season.

The 1992 planting had 78.7% survival at the end of its first growing season and by the end of the second growing season (1993) survival was 70.3%. Overall vigor for the 1992 planting ranged from 4.3 (fall, 1993) to 4.7 (fall, 1992). Overall uniformity at the end of the second growing season was rated at 4.6.

The 1993 planting had 44% survival at the end of the first growing season. Overall vigor was 5.8 and overall unifomity was rated 6.0. Although ideal weather conditions (cool and wet) at planting time existed, the low survival rate is most likely attributed to irrigation problems.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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The increase in survival from the first year of planting to the second year of planting is mostly due to re-sprouting of cuttings. Woody plant material will self-regulate leaf area. If there is too much or too little water, trees and shrubs will lose their leaves to conserve energy. In many cases, cuttings will develop leaves after they are planted, then drop their leaves later in the season, giving the appearance that the cutting is dead. Also, in some cases, newly planted, rooted material will also appear dead in early fall.

Comparison of the stock planted indicate that potted and bareroot survival are 90% and 87% respectively, versus cutting survival of approximately 75%. Although the cutting survival is very good, rooted material appears to have a better chance of survival.

After two growing seasons there appears to be some accessions that are replicated which are outstanding. The best low growing shrubs from the 1991 planting, Mackenzie willow (20100), Blue arctic willow (9005050), Lemmon willow (20121), and Redosier dogwood (23739) exceed the average for all traits evaluated. Two accessions from the medium height group had above average survival and the only accession which exceeded all traits was chokecherry (9004629). None of the tall trees from the 1991 planting exceeded all the traits. However, as a group, their survival and vigor are the best as compared to the other growth forms. It is very likely, that as the plants mature, some accessions will perform consistently better than the group overall.

Display accessions noted as having good early progress were: 'Cling Red' amur honeysuckle, 'Freedom' honeysuckle, and "mitosis" honeysuckle. Tall trees showing good promise for windbreaks were 9039340 plains cottonwood, 9016289 robust poplar, and 9047349 golden willow.

PLANTS: Plant Data for Natural Resource Planning[1]

Lyn Townsend and Wendall Oaks[2]

PLANTS is a dynamic US Department of Agriculture database (USDA) that provides the USDA-Soil Conservation Service (SCS) and its customers with a standardized set of nomenclature and data about plants and ecosystems. The database effort began in 1989 and currently contains a list of 46,000 North American flora. The database is operational at USDA Computer Centers at Kansas City, Missouri, and Ft. Collins, Colorado. The access and query software to the database and the data are being developed by the SCS Information Resources Management Division at Ft. Collins. This effort is part of the USDA Info Share "Fast Track" initiative.

The ultimate goal is to have PLANTS serve as the defacto standard for Team USDA:

Agricultural Research Service, Animal and Plant Health Inspection Service, Forest Service, Soil Conservation Service, Bureau of Land Management, Fish and Wildlife Service, National Park Service, US Army, Extension Service, Agricultural Stabilization and Conservation Service, Farmers Home Administration, and Federal Highways Administration. Of course, all partner state and local organizations will be able to use and access PLANTS.

One of most exciting uses for PLANTS will be using the nearly 100 data elements per species as the foundation database to operate "VEGSPEC". VEGSPEC is software that will enable natural resource professionals throughout the nation to develop site-specific specifications for vegetation establishment practices. Practices under development are Field Windbreak, Farmstead Windbreak, Cover Crop, Critical Area Planting, Filter Strip, Pasture and Hayland Seeding, Range Seeding and Tree Planting. Specifications for these practices can be combined into "agroforestry systems." The VEGSPEC software is planned for distribution in April 1996.

Within the USDA-SCS, PLANTS will be integrated with companion databases: Soils/Geology, Water, Atmosphere, Animals, and Base Cartography/GIS. These databases and access/query software are merged into the Field Office Computing System (FOCS) available to Team USDA. SCS field offices are currently being trained in FOCS with full implementation and use by December 1994.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Activities of the International Centre for Research in Agroforestry (ICRAF)[1]

Brad Tyndall[2]

ICRAF is an autonomous, non-profit international organization whose ultimate purpose is to "help mitigate tropical deforestation, land depletion, and rural poverty through improved agroforestry systems."

Established in 1977, ICRAF has its headquarters in Nairobi, Kenya and its research activities expand into over 13 African countries, Peru, southeast Mexico, and Indonesia. In 1991, ICRAF expanded its scope and potential when it became a strategic research center of the Consultative Group on International Agricultural Research. ICRAF has more than 250 staff members, including about 50 senior scientists, and receives financial support from 26 donor organizations which amounted to $13.4 million in 1992. Collaborating governments provide staff, facilities, and land for field trials.

ICRAF's research, based on collaboration with national scientists and farmers, is divided into four research programs: Characterization and Impact, Multipurpose-Tree Improvement, Component Interactions, and Systems Improvement. In addition, ICRAF has three dissemination programs: Training, Education, and Information.

At present, ICRAF concentrates in four ecological regions of Africa: the humid lowlands, the semiarid lowlands of western Africa, the highlands of eastern and central Africa, and the plateau lands of southern Africa. Research in these regions is conducted through the Agroforestry Research Networks for Africa (AFRENAs). ICRAF also participates in collaborative research in India and Bangladesh, and has initiated activities in the humid tropics of Latin America and Southeast Asia.

In addition, ICRAF is coordinating the African Highlands Initiative. This long term project aims to develop an integrated research program for better management of natural resources. The collaborative initiative is a joint effort of ten international research centers and the national agricultural research systems and nongovernmental organizations (NGOS) from the countries involved.

Also, ICRAF is chairing the global steering group of the Alternatives to Slash-And-Burn Initiative. This 10-year initiative which involves a total of 18 national programs, international research centers and NGOS, aims to reduce deforestation caused by unsustainable slash-and-burn agriculture by providing technology and policy options. In March, 1994 the United Nations Development Program began to provide funds for the first phase which will focus on sites in Indonesia, Brazil, and Cameroon. Future sites will be in Peru, Zambia, Thailand, the Philippines, and Mexico.

* For more information about ICRAF or its activities, contact Mr. Michael Hailu, Information Program Coordinator. P.O. Box 30677, Nairobi, Kenya. Telephone (254-2) 521450. Telefax (254-2) 521001. E-mail CGI236. Telex: 22048.

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[1] *Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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Riparian Buffer Strip Demonstration in Iowa[1]

Richard L. Wiest[2]

Trees have been removed along the stream channels in the Central Plains States and these areas are now being cropped or grazed. In order to reverse this trend, a demonstration project was installed in central Iowa at the site of the 1993 Farm Progress Show. This Show commonly attracts about 250,000 farmers from the agricultural regions of the Central US. The purpose of this demonstration was to show the potential of using fast-growing trees as an alternative to farming the riparian areas.

Hybrid poplar was chosen for this demonstration because of its fast growth rate, ability to resprout when cut, ability to root from cuttings, hardiness of some varieties, availability, and testing.

The poplar tree buffer concept is an alternative stream management practice that reduces nonpoint pollutants entering creeks while growing a woody fiber crop intended to provide sufficient cash value for the landowner.

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[1]*Poster presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

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